Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 192 NOVEMBER, 1921 No. 5

THE SCIENCE OF ELECTRIC WELDING.*

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INTRODUCTION.

THE art of welding iron is undoubtedly one of the first acquired by man in his use of this metal, for it was only by its practice that the iron, produced by the early low temperature reduction processes, could have been associated into a mass of useful proportions. This art reached its zenith during the period of the fifteenth to the eighteenth centuries as expressed in the magnificent screens and grills at Florence and Verona, and in England.

Up until the nineteenth century the blacksmith's hammer and anvil were the only known tools for welding, but the progress of time has substituted a new method of joining metals by fusion, first, by the use of compressed gases and latterly by the use of electrical energy.

The title of this paper represents, possibly, more of a hope than an accomplished fact. Much of the "art" still clings to even the most modern practices in electric arc welding. However, our present day industries require the closely controlled and definitely reproducible processes of science and the progress of recent years has indeed gone far toward placing this art of welding on a scientific basis. The work of the Welding Committee of The National Research Council has done much toward the accomplishment of this end.

* Presented at a meeting of the Electrical Section held Thursday, March 24, 1921.

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HISTORY.

The use of electric energy for joining metals had its inception along about 1874, when Werderman proposed to use the heat of a carbon arc deflected to the point of use by a jet of air. This idea was later improved upon by Zerener, who deflected the arc by means of a magnetic field. Both of these processes required considerable time and skill for their application, and neither ever attained any commercial importance. Credit for the first arc welding, as it is now applied, is generally attributed to de Meritens, who in 1881 used an electric arc from a carbon

FIG. 1.

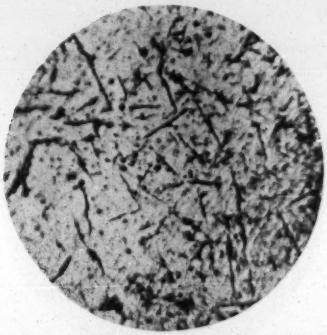
Oxide and nitride in deposited metal. ×75.

electrode to weld the lead of storage battery plates. A few years later this process was extended to welding other metals by Benardos, of St. Petersburg. A further development is due to Slavianoff, who substituted a metal electrode for the carbon and used the molten metal from this electrode for filling blow holes and cracks in defective castings. For many years the application of these processes languished for want of proper electrical machinery for generating and applying the energy needed, and the progress made goes hand in hand with the perfection of electrical equipment, which has been rapid during the last ten years.

About the same time as these beginnings were being made in arc welding, Elihu Thompson, in 1877, experimenting in the Laboratory of The Franklin Institute here at Philadelphia, conceived

the idea of joining metals by the resistance method, and in 1886 made public his first apparatus. This was designed to hold together two pieces to be welded, while passing a heavy current through them until the abutting edges reached fusion and joined under the pressure applied. Modifications of this butt welding quickly followed in spot, ridge and seam welding. The latest development along this line is percussion welding, which differs only in the character of the energy applied. In this case a sudden rush of stored up current from a condenser or magnetic field is applied and at the same instant union is obtained by pressure on the parts.

FIG. 2.

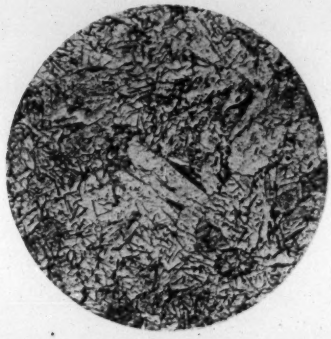


Same as Fig. 1—annealed. ×75.

By this method a greater concentration of energy is obtained than in spot or butt welding, there is less "flash" or extruded metal, different metals are readily welded together and due to the concentration and short duration of the heating a minimum amount of metal is affected by the heat. It is estimated that the time of fusion and union is about .0095 sec. At least three-fourths of the power is saved as compared with butt welding. Unusual welds may be made, such as welding small rods to heavy blocks without previous treatment of the surfaces. As only a very small area is heated it may be safely used when loss of temper would be injurious. Unlike metals are readily welded and the quality of the weld, after proper adjustment, is independent of the skill of the operator.

The most recent researches in spot welding as a substitute for riveting have been along the line of developing machines for spot welding heavy sections. These have been built for welding through 1″ thicknesses of plate. Such a machine has a current capacity of 100,000 ampères and is capable of exerting a pressure of 75,000 pounds. Duplex machines having a six-foot span, and designed to weld two spots at a time have been used to a limited extent to replace riveting machines. It is estimated that there is a saving of 25 to 50 per cent. in time by using spot welding as compared with riveting, if the time of punching holes, laying out, lining up, etc., is counted.

FIG. 3.



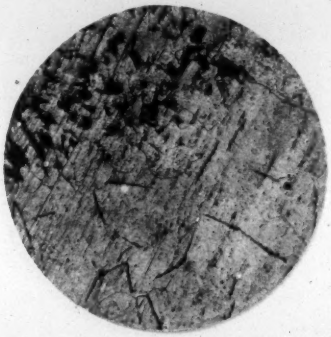
Deposited metal. ×75.

Spot welding machines, particularly when heavy currents are required, are heavy and for use where portability is necessary, require crane service. The single-phase current used is also a disadvantage, for power companies object to the unbalancing of their systems. When small equipments are used this disturbance is not serious, or if a number of welders are used they may be distributed among the various phases of a polyphase system. The actual cost of power per weld is very small, and the saving over riveting, under constant service conditions, would easily pay the investment charges on a motor-generator equipment to correct defects in loading electrical systems.

Resistance welding, in its different forms, quickly found many applications, its chief development being in the perfection of automatic machines for handling large production of like pieces. Hoops, tires, chain links, wire fence, lathe tools, kitchen utensils, iron ladders and gratings, and a large variety of other products are now welded in these automatic and semi-automatic machines.

The recent increase in the application of electric welding, particularly of arc welding, has given rise to many questions having to do with the quality of the product and its trustworthiness under severe service conditions. During the war the National Research Council and Emergency Fleet Corporation appointed a welding

FIG. 4.



Annealed weld, showing boundary between plate and weld. ×75.

committee to study the problem in connection with the welding of ship plates. This committee did much to stimulate research on electrodes, current strengths, the nature of the arc, inspection methods and the instruction of welders.

CARBON ELECTRODE ARC WELDING.

This, the oldest of the arc processes, is still being used to quite a large extent. Although the use of the metallic electrode has received a large share of attention and publicity in recent years, this process still has its distinct field of usefulness which should not be overlooked. It is used in four ways: By using the heat of the arc to fuse together abutting edges of metal sheets or plates; by fusing

a metal filling rod into the space to be welded; by combining the metallic and the carbon arc, and for cutting.

The electrodes are of carbon or graphite, according to preference of the welder. Some users claim that a lower rate of consumption and a softer weld is obtained from the latter. The size is determined entirely by the current to be used and varies from ¼″ tapered to ⅛″ for currents of 50–150 ampères on light work, to 1½″ tapered to ⅛″ for 800–1000 ampères for use on very heavy melting and cutting work. The electrodes are always tapered and this original taper is maintained by the electrode. This taper makes the arc more stable and easily controlled.

FIG. 5.

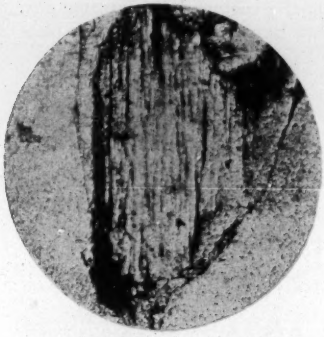
Boundary between plate and weld. Note coarsened grain of plate stock. ×75.

As the positive terminal of an arc attains a much higher temperature than the negative the metal to be welded is usually made positive. This results in a minimum heating of the electrode and a more stable arc. Even when made the negative pole, the carbon heats considerably, causing much burning and vaporization of the carbon. If carelessly handled much of this carbon finds its way into the fused metal, hardening it to a great degree. If the arc length is properly maintained much of this carbon vapor is burned in the arc stream. The arc length, although flexible, should seldom be less than ½″ and except for very high currents should not exceed 1″, to obtain a soft weld with a minimum of oxidation.

Without the use of filling material, the process is used for

welding flanged edges of sheet steel and non-ferrous metals, and for cutting. With a filling rod it finds its chief application in the welding of cast iron and cast steel, filling in defective spots and building up worn surfaces. The combined carbon and metal arc processes are used where careful preheating is necessary as in cast iron. The carbon arc is used to preheat the surface around the point to be welded and the metal arc used for the actual welding operation.

FIG. 6.



Slag inclusion in weld, covered electrode used.

On the whole, the carbon arc process requires less skill than the metallic arc and, for welding light plates and sheets, filling in defective castings and cutting off risers for castings, it is cheaper than any other process.

METALLIC ARC PROCESS.

A rapid advance in the knowledge of metallic arc welding has taken place in the last decade. A great impetus to its study came from the war demand for ships. It then became important to know as quickly as possible what electrodes to use, what current density was best, how to prepare the edges for welding, how much the weld would stand, and how reliable was one weld as compared with another made under like conditions.

The making of a good weld is essentially a metallurgical problem. The study of electrode materials, the deposited metal and the

mechanism of transfer from the one to the other through the arc stream have been of particular interest to the present writer, and the results of this study will be discussed in some detail.

METALLOGRAPHY OF WELDS.

The physical properties of a weld or of any steel casting will depend upon the grain, solidity and chemical composition. Unfortunately the conditions under which a weld must be made are such as to effect these factors unfavorably. The grain is usually coarse, due to the method of cooling, but a skilful welder can produce a fine grained structure by depositing the metal rapidly in comparatively thin layers. In this way the plate is not heated up

FIG. 7.

Plate stock—mild steel. ×75.

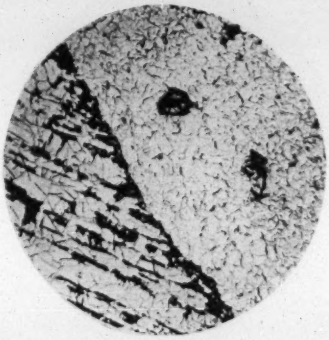
sufficiently to slow down the cooling of the deposited metal, and each successive layer serves as a partial heat treatment to those underneath.

Gas holes are found to a greater or less degree in all welds. They may come from the use of an electrode that is too high in carbon and other gas forming impurities, but most frequently are caused by the highly oxygenous weld metal coming in contact with the carbon in the fused plate metal. They are minimized by using as short an arc as possible, depositing the metal rapidly and keeping the impurities low in the plate metal. Occluded gases in the electrode have little effect in this respect, but have a very bad effect on the solidity of the weld if present in the plate metal.

Slag inclusions (Fig. 6) are a common source of weakness in welds and are due almost entirely to poor workmanship. One layer is put over another without proper cleaning or the pool is not kept molten long enough to float off the slag formed from the oxidation of the electrode. Particular care must be taken when working with coated or filled electrodes. Wrought iron electrodes can also give trouble in this respect.

The two most important elements present in the weld material are oxygen and nitrogen (Figs. 1–8). Both may be present in amounts sufficient to be harmful to the ductility of the deposited metal. Some oxygen is held in solution in the iron, but usually it may

FIG. 8.



Annealed plate and weld boundary. Note penetration of N into plate. ×75.

be seen in small patches or spots. Welds are never free from it, but usually there is not sufficient present to account for the usual lack of ductility. It is probably also present in the form of a thin film around the grains, but this is not visible under the microscope. Until a few years ago the presence of nitrogen was not given serious consideration. A thorough study [1, 2, 3, 4] of certain characteristic structure always found in welds proved, however, that

[1] Structure of Fusion Welds. S. W. Miller, *A. I. M. E.*, 58, 700 (1918).

[2] The Metallurgy of the Arc Weld. W. E. Ruder, *G. E. Rev.*, 21, 941–6, (1918).

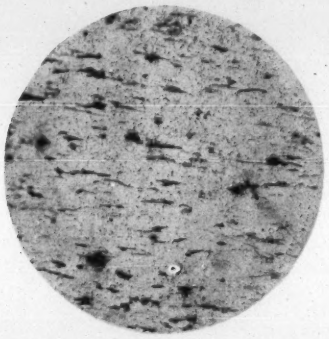
[3] Nitrogen in Steel. Comstock and Ruder, *Met. Chem. Eng.*, 22, 399 (1920).

[4] Nitrogen and Erosion in Guns. Wheeler-Discussion (Ruder), *A. I. M. M. E.*, Feb. (1921).

this element was not only present in amounts up to .15 per cent.–.2 per cent., but was a most important factor in causing "cold-shortness." The effect of heat treatment was studied and a new method of etching was developed [4] which distinguished between the nitrogen bearing areas and other metallographic constituents.

It may occur as needles, eutectoid patches or surrounding the grains as a film of varying thickness (Figs. 11–22, inc.). As little as .06 per cent. *N* will reduce the elongation in a .2 per cent. C. steel from 20 per cent. to 5 per cent. Under ordinary conditions of fusion *N* has little effect on iron, but under the conditions of the electric arc the gas molecule is broken up and the *N* atom readily

FIG. 9.



"Pure" iron welding rod. ×100. This rod has excellent welding properties.

combines with the molten iron particles and iron vapors.

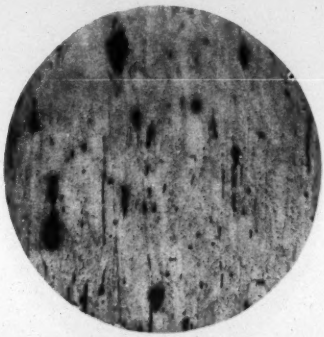
Both the oxygen and nitrogen content of the fused metal are probably kept at a minimum by using a short arc in depositing the metal and by maintaining a current value which does not exceed that necessary to fuse and transfer the metal. Excessive current will increase the oxygen and nitrogen content to a point where the deposited metal will be excessively brittle.

S. W. Miller [5] has shown that the path of rupture in steel fusion welds does not bear any relation to the nitride needles, and concludes from this that their presence is not a direct cause of brit-

[5] Miller, Path of Rupture in Steel Fusion Welds, *Bull. A. I. M. E.*, No. 146, Feb., 1919, p. 311.

tleness in welds. The point that should not be overlooked in this connection, however, is that nitrogen in steel acts like carbon in this respect, that it is the N remaining in solution in the ferrite that causes the brittleness. The N-needles, as I have shown,[6] are produced by slow cooling, and their presence indicates that nitrogen is present, but does not mean that all the nitrogen has been released from solution in the ferrite, nor does their absence indicate the total absence of nitrogen (Figs. 21 and 22). A rapidly cooled weld may contain as much at .1 per cent. N, and still appear under the microscope as pure ferrite (Fig. 21).

FIG. 10.



Steel welding rod. ×100. This rod contains much gas. Requires dipping for good results.

The needles present merely represent an equilibrium between the dissolved nitride and that precipitated from solution under the particular conditions of heating and cooling. Interesting data confirming this are given by Owens, Ramage and Watts, in a paper recently presented before the American Welding Society, in which they show that the ductility of a weld is greatly increased by slow cooling from 1200° F. Their micrographs also show the same changes in structure due to heat treatment as those of nitrogenized iron.

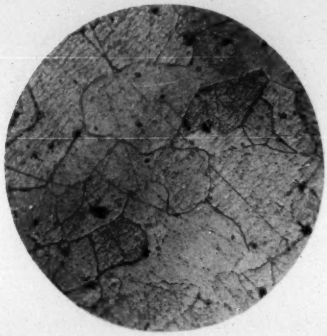
METAL TRANSFER.

The metal from the electrode is transferred to the weld partially by vaporization and condensation, partially by expulsion of

[6] Comstock and Ruder, *Chem. Met. Eng.*, 22, 399 (1920).

the molten metal due to the explosion or rapid expansion of gaseous products formed by oxidation in the electrode tip, and partially by surface tension and gravity. Although in normal welding practice the largest amount of metal is transferred by the last method, the expulsion of particles of molten metal by gases plays an important rôle. If gas-forming impurities are not present in some degree, the metal will transfer, but the deposit so formed will not "bite in." The metal drops transfer by the molecular attractive forces, but act more like molten solder. Overhead welding under these conditions is almost impossible because the drops formed become so large that the force of gravity overcomes that

FIG. 11.



Same as Fig. 9—annealed. ×100. Good welding properties.

of surface tension, and the metal drips down the side of the electrode.

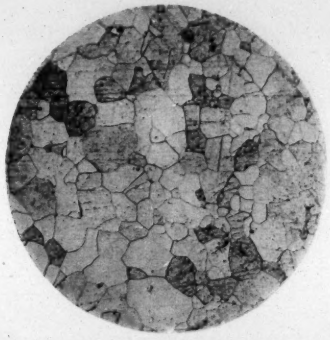
The action is somewhat improved, by reversing the polarity from negative to positive, due to the more rapid heating and greater vaporization of the electrode. The sudden expansion of the metal vapors, in this case, supply some projecting force, but not enough to give a satisfactory penetration, which should be at least $^1/_{16}$" as determined by the depth of the arc crater. Ordinary mild steel and commercial ingot iron electrodes usually contain enough carbon and slag to give the necessary "kick," and extreme care must be taken to have a very pure wire if the effect of the absence of impurities is to be noted. Failure to note this has led some

investigators to reject, as irrelevant, the gas propulsion theory originally proposed by Hudson; the assumption having been made that the wire used was "pure" because it was so labelled by the manufacturer.

ELECTRODES.

These may be divided into two general classes—bare and flux covered. For most work, in either case, a mild steel wire, varying in thickness from $^3/_{32}''$ to $^3/_{16}''$, is used. The diameter depends on the size of the weld to be made, and therefore upon the amount of current to be carried. The smaller diameter bare wire ($^3/_{32}''$) is used for currents of from 50 to 75 ampères and the larger ($^3/_{16}''$)

FIG. 12.



Same as Fig. 9—purified. ×100. Will not weld under any treatment.

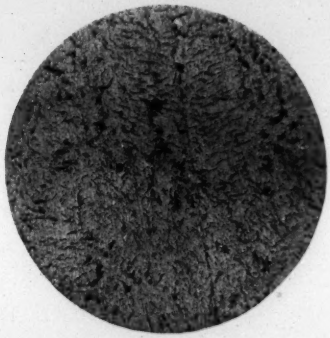
for currents of from 185 to 275 ampères. For covered electrodes these values should be cut to about one-half. The composition is approximately C. .18 Si. .08 Mn. .50 S. .05 P. .05 (max. value). In passing through the arc most of these impurities are oxidized and do not appear except in much smaller percentages in the deposited metal, but others, oxide and nitride, do appear and are kept at a minimum by the maintenance of a short arc ($\frac{1}{8}''$).

If electrodes are pickled, excessively rusted or contain too much carbon, sputtering results due to the generation of gases from the carbon and atmospheric oxygen or the liberation of occluded gases. This condition may usually be remedied by dipping the electrodes in lime or various other coating materials which serve to steady

the arc. Some manufacturers produce wires which are quite true to composition, but vary considerably in operation. In several cases this has been traced to excessive gas content in the wire. Another wire manufacturer produces a wire advertized as being of high purity. This wire works well all the time, but its good operation depends upon its slag content, for if it is further purified by removing this slag it makes a very poor welding wire indeed.

Many attempts at improving the ductility of the weld by adding various deoxidizing or denitrogenizing elements to the electrode have been made, but none has been entirely successful, due to the fact that any such element (Al, Ti, V, B. etc.), is rapidly attacked

FIG. 13.



Weld made in nitrogen gas. ×75.

and lost during its passage through the arc stream. To be most successful such an element should be added to the plate material or the molten pool with fusion maintained for a sufficient time to float off the slag products. This is always important, but particularly so when slag covered electrodes are used, to insure proper puddling of the fluid area in order to release entrapped slag and to give it an opportunity to combine with the iron oxide present.

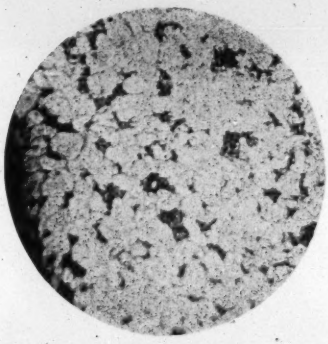
RELIABILITY OF THE WELDED JOINT.

There is now a mass of data to show that a welded joint, provided it was conscientiously made by one skilled in the art, is a good engineering risk. Arc welded butt joints can be counted on

to have at least 90 per cent. of the strength of the plate, and spot welded joints are stronger than riveted joints. Although there is still considerable room for improvement in ductility, actual experience with welded joints has shown this lack of ductility to be of less importance than it was first feared it might be, particularly in welding soft steel.

These statements presuppose to fact that the weld has been well made. A proper inspection of welds is imperative, yet it would be difficult to describe what a good weld should look like. Such knowledge is only to be obtained by experience resulting from destructive tests of a large number of welds. For this reason

FIG. 14.



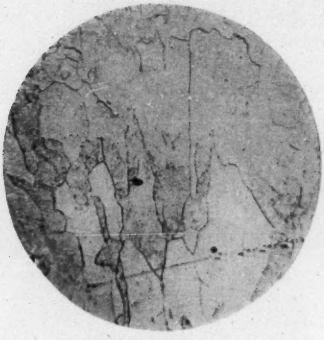
Weld made in CO_2 gas, no nitride present. ×75.

emphasis must be placed upon the thorough training of the welder which will allow him to test his product by bending and deep etching until he can make satisfactory welds every time.

The bending test, made by clamping the welded piece at the point of the weld and hammering one end until the weld opens up, will disclose defects due to improper joining with the base metal and excessive slag inclusions. The deep etching test made by cutting a section through the weld, polishing and etching in hot 25–50 per cent. hydrochloric or nitric acid will disclose inclusions and porosity otherwise invisible (Figs. 23–24). This etching will also disclose the structural change which has taken place in the base

metal. This change is very important, particularly when medium or high carbon steels are welded. It is caused by a solution of some carbon, present normally as pearlite, and by a coarsening

FIG. 15.



Weld made in hydrogen. No oxide or nitride present. ×75.

FIG. 16.

Pure iron—nitrogenized by heating in ammonia. ×75.

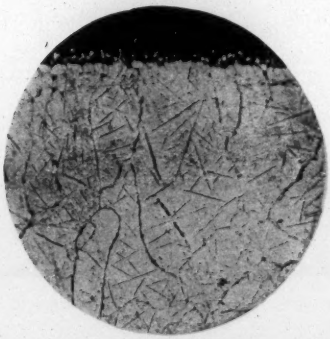
of the grain, both of which tend to embrittle the metal. Such conditions are corrected by annealing after welding, and for this reason steels of high carbon (over .3 per cent.) or alloy content

are satisfactorily welded only if preheated and subsequently annealed. Such annealing will also relieve internal stresses in hard materials, castings, etc.

FIG. 17.

Same as Fig. 16—quenched in water from 700°C. ×50.

FIG. 18.



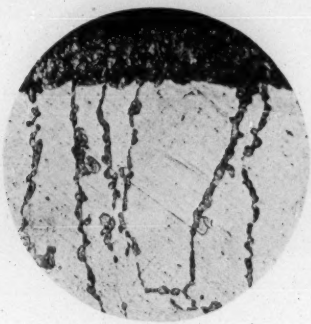
Same as Fig. 17—reannealed.

Magnetic, resistance, and X-ray methods have been suggested as non-destructive tests for welds, but none of these have yet been perfected to a point where they can be easily applied to commercial products.

ELECTRICAL CHARACTERISTICS AND EQUIPMENT.

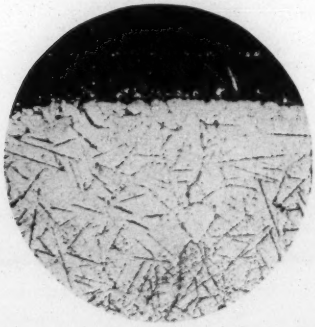
During the past few years the technical and engineering press has been flooded with articles dealing with the various applications

FIG. 19.



Same as Fig. 16—quenched from 800°C. in water. ×50.

FIG. 20.



Same as Fig. 19—reannealed. ×50.

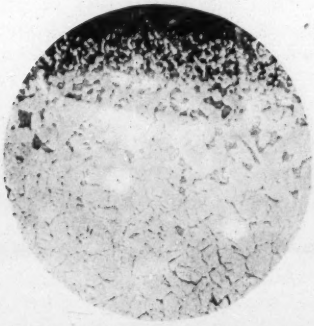
of welding. The selling price of arc welding apparatus exclusive of accessories and supplies, sold in the U. S. during 1920, is estimated at approximately $2,000,000. Accessories and supplies, such as electrode material, etc., will probably amount to $2,500,000.

The apparatus generally consists of standard material such as motor generators, switch boards, motor starters, etc., with more or less minor changes to make the equipment suitable for arc welding

FIG. 21.

Same as Fig. 16—quenched in water from 950° C.

FIG. 22.

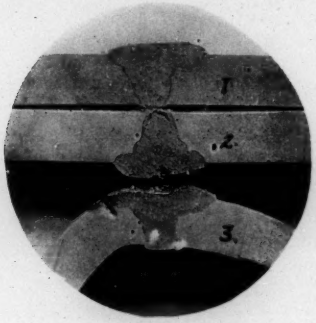


Same as Fig. 20—reannealed. ×50.

service. The demand for this equipment appears to be more settled than that for other electrical equipment, for when business conditions are such that ordinary purchases of equipment are deferred, arc welding becomes of greater importance for salvaging

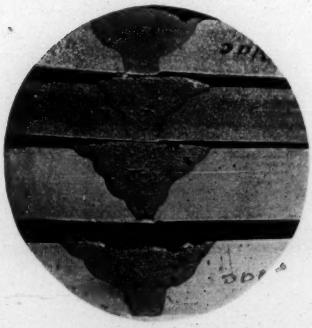
and repairing used or discarded parts. This has a tendency to keep up the sales of arc welding apparatus to somewhere near the normal level.

FIG. 23.



Deep etched welds. Note improper joining at base of V in 2.

FIG. 24.



Deep etched welds. ×½.

ALTERNATING VERSUS DIRECT-CURRENT WELDING.

Direct-current welding is in most general use in this country, and in its simplest form, requires only a rheostat of sufficient capacity and a D. C. source of current supply. Unfortunately,

however, this is seldom available, so that a motor generator set is required. The generator is especially designed to have the proper characteristics for arc welding service. This generator is driven by a motor of standard construction to meet the need of the available supply circuit, and the only concern of the central station is that the circuit is of sufficient capacity to drive the load, as the equipment has the commercial power factor of an ordinary induction motor load. The inertia of the revolving parts tends to cushion somewhat the sudden load changes as the arc is struck or broken.

There is still some difference of opinion as to what are the proper characteristics for the generator supplying energy for arc welding. It appears, however, that the ideal condition for obtaining a good weld on a given piece of work is obtained when current and voltage at the arc are constant. With a manually controlled arc this condition is impossible of entire realization. To make conditions as near the ideal as possible a constant energy set has been developed, the principal advantage of which lies in the fact that it facilitates the maintenance of a short arc and makes it difficult to keep a long arc. As the rate of consumption of electrode material depends upon the current and is independent of the voltage, a shortening of the arc causes more rapid electrode consumption with a consequent return of the arc length to normal.

The load factor of a single operator arc welding equipment varies from 5 per cent. to 70 per cent., depending upon the kind of work done and the method of handling it. The capacity factor is probably half of this figure, since only a small portion of the work requires the full output of the welding equipment. In the case of a large multi-operator, constant potential equipment, the capacity factor may be increased considerably.

There has always been a certain amount of conflict in reports of tests of welds made with an A. C. or a D. C. welding system. If the comparison is made without prejudice I believe that each system has its distinct place in industry. As compared with direct-current system, alternating-current systems have the advantage of low first cost of equipment, and for the small repair shop this is of some importance. Against this we have the disadvantage of low-power factor (20–40 per cent.), single-phase operation, and greater difficulty in arc maintenance. These objections are very real and have led many engineers to decide against the use of A. C. There

are many small construction and repair shops, however, where an arc welding set would be of great service, but where the installation of a D. C. equipment is out of the question due to first cost. In such cases A. C. welding could be used to advantage, for the small load would not greatly unbalance the system or the low-power factor greatly disturb the central station.

Carefully made experiments have shown that there is little to choose between in the quality of the welds produced by experienced operators, with either system. A. C. welds have frequently been condemned because the job was not done with sufficient care, and the arc was not maintained with sufficient skill. If this is done, there does not appear to be any essential difference in the character of the metal deposited.

Some claim has been made for A. C. welding systems that they operate from polyphase circuits, but this does not mean that the load is balanced. A single-phase load cannot be transformed into a balanced three-phase load by static transformers alone. Such a condition creates as much or more disturbance as does an unbalanced current load, and some electricity supply companies have prohibited the use of A. C. arc welders on their lines.

AUTOMATIC ARC WELDING.

Just as the increased use of resistance welding quickly brought into use automatic devices for increasing speed and reliability of product, so the automatic electric arc welding machine promises to find an important place in this form of welding. This machine will weld at a speed of from two to six times the rate possible by skilled operators welding by hand, due to the stability of welding conditions and the elimination of the necessity for changing electrodes.

The characteristics of practically all electric welding circuits are such that the current and voltage are interrelated, an increase in one causing a corresponding decrease in the other. The automatic arc welding machine utilizes the arc voltage as a basis for regulating the equipment. A shunt wound motor having the armature connected across the welding arc will vary in speed as the arc lengthens or shortens, due to the variation of the arc voltage. Now, if this motor is connected through suitable gearing to the electrode wire, the wire will be fed into the arc at a rate depending upon the arc voltage it is desired to maintain. A vibratory relay is also connected across the circuit in such a way that the relay

contacts open when the voltage increases. This cuts resistance into the field circuit of the feed motor, still further tending to increase the feeding speed. As a result, the wire is continuously fed into the arc at an almost constant rate, and the electrical conditions, as indicated on the switchboard instruments, are very steady.

As is the case with other automatic machines, the principal field for the automatic arc welder is one where a considerable amount of welding is required, calling for a continuous repetition of duplicate welds, building up pulleys, shafts or worn bearings. Unland [7] gives an example of the saving in cost in welding crane wheel flanges. These were repaired at a cost of $4 by automatic welding and $9 by hand welding.

CONCLUSION.

Of the application of electric welding in its various forms to our present day industry volumes have already been written. In a multitude of applications it has proven not only its economy but its entire reliability. Although the quality of the weld is still largely dependent upon the skill of the welder, through the application of scientific knowledge in the perfection of electrical equipment, the selection of materials and the training of welders, the title of Science has at least a foundation in fact.

BIBLIOGRAPHY.

A very complete bibliography of books and articles published on welding has been published by Jacob G. E. Rev. 21 (652–658) 1918. This includes all publications between 1914–1918. For earlier works, W. B. Gamble, of the New York Public Library, published a bibliography covering the period 1786–1913. This was published by that Library in 1913.

Sodium Carbonate, Hydrated. (*U. S. Geological Survey Press Bulletin No. 478*, October, 1921.)—Sal soda, hydrated sodium carbonate, washing soda, or crystal carbonate, having the chemical formula $Na_2CO_3.10H_2O$, is made from soda ash by dissolving it in water and allowing the solution to crystallize below 32° C. It is used in softening water and for many other purposes for which soda ash is used where purity is an essential requirement. It is also used in cleansing compounds or alone as washing soda.

According to the Survey, the production of sal soda in the United States in 1920 was 62,857 short tons, valued at $128,937.

[7] *American Machinist*, Aug. 26, p. 405 (1920).

Reduction by Zinc and Cadmium.—Zinc has been long used for reducing ferric salts in the analysis of iron compounds. TREADWELL (*Helv. Chim. Act.*, 1921, iv, 551) presents the results of an elaborate investigation made by Lüthy and Rheiner into the common methods and a comparison of the zinc method with that of cadmium. In the original process the zinc was used in fragments, but Carnegie, in 1888, introduced the use of the powdered metal by which much more rapid action is produced. Many trials and improvements were introduced, by which the reduction was greatly expedited without material sacrifice of accuracy. Treadwell's paper gives the results of many experiments, the conclusion being that finely divided cadmium is adapted to the determination of iron, titanium and mixtures of the two, as well as for molybdenum, vanadium and uranium. The zinc reduction was found to be satisfactory for iron.

H. L.

Comparison of Cost of Electric and Fuel Furnaces.—Patch, in a communication to the fortieth meeting of the American Electrochemical Society, held recently, has made a careful comparison on this question, and expresses the opinion that the costs are substantially the same if proper attention is given to the details of operation. Contrary to what might be expected, *a priori*, the solution of gases in the molten metal is about the same in both systems. The claims of makers of electric furnaces for marked saving in melting-losses were not confirmed, though certain alloys may be more economically treated by the electric method. Some weight must, however, be given to the cleanliness of the electric furnace and the more comfortable operating conditions. In this connection, probably, Patch includes the avoiding of the smoke nuisance, which is certainly a most important matter as regards the public at large. Obviously, as pointed out, cheap electric power will change the relations of the figures; on the other hand, advances may be made in the operation of fuel-firing which will give such methods an advantage over the electric. Alloys sensitive to hydrogen, superheated nitrogen and to carbon will be more satisfactorily treated without fuel.

H. L.

Atomic Weight of Cadmium.—GREGORY PAUL BAXTER and CARL HENRY WILSON, of Harvard University (*Jour. Am. Chem. Soc.*, 1921, xliii, 1230–1241), have determined the atomic weight of cadmium by analysis of cadmium sulphate in the electrolytic way, using a cathode of pure mercury for the deposition of the cadmium. Their results give 112.41 as the minimum value for the atomic weight of cadmium.

J. S. H.

RECENT ADVANCES IN THE PRODUCTION AND APPLICATION OF X-RAYS.*

BY

J. S. SHEARER, B.S., PH.D.

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THERE have been from time to time during the century past some remarkable discoveries destined to cause profound changes in human thought and mode of life. Some of these have become so quickly and firmly incorporated in our environment that we have hardly realized their origin and rapid development. In theoretical and applied electricity are some of the most striking examples of such developments, having wrought such wonderful results that one can hardly realize their ramifications.

Measured in terms of the duration of human history, all electrical knowledge is recent and most of the practical applications were made within the memory of those who are near to man's allotted three score years and ten. In Denmark there has just been celebrated the one hundredth anniversary of Oersted's discovery of the relationship between electric and magnetic phenomena. A few years after Oersted's work, Henry and Faraday laid the foundation for the marvels to be accomplished in applied electricity. Less than fifty years ago the first power motor made in America was completed and one of the designers is still living. Many of the pioneers in the development of the arc and the incandescent lamp and of the telephone are still active.

Twenty-five years ago this month there was announced a new wonder, the culmination of a long series of experiments, the starting point of a new line of endeavor, giving rise to concepts, unrivalled in scope and daring, and, curiously enough, resulting in theories strangely related to those of the master mind whose honored name is borne by this society.

A careful and well-trained observer, already well known in his chosen field, Röntgen not only announced a type of radiation whose existence had not been suspected but he described, with

* Presented at a meeting of the Section of Physics and Chemistry held Thursday, December 9, 1920.

wondrous simplicity and clearness, experiments performed to ascertain its nature and to properly place it in the scheme of physical science.

I well remember in Dr. E. L. Nichols' physics seminary the mention of a rumor that a radiation had been found able to pass through opaque objects, not capable of refraction or reflection and otherwise strange in its nature. Curiously enough it did not strike us as at all peculiar that light should penetrate glass or water or that radiant heat should pass through opaque hard rubber, but the announcement of rays that would pass through aluminum or the human body was received with hardly tolerant skepticism.

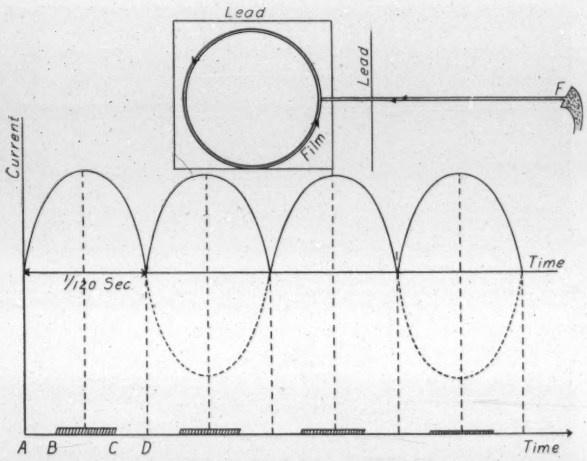
Briefly stated Röntgen showed that peculiar rays were produced by electric discharge through a highly exhausted tube. They were able to excite fluorescent light in certain materials and to affect a photographic plate. They were not refracted or reflected, were propogated in straight lines, and were able to produce secondary rays possessing like properties. Materials varied in transparency to this radiation somewhat in the order of their densities. In his first announcement he was not certain as to the point of origin of the rays or the basic mechanism of their production. He used an induction coil and, initially, tubes that had been designed to demonstrate previously known phenomena. In fact the presence of a card covered with crystals often used in cathode ray tubes led to the discovery.

In a comparatively short time it became clear that the rays originated mainly, at least, at the surfaces of objects within the tubes or in the glass walls, and very soon the curved cathode of Crookes and the metal target gave us the "focus" tube. These early tubes were operated either by induction coils or by "static" machines and carried very little electric energy. The demand for rapid radiography resulted in the development of more powerful coils and the slow evolution of tubes with massive metal targets, water cooling, etc., to enable more rapid work. Meanwhile but little advance had been made in basic theory or in applications outside of medicine and surgery.

Let us consider first the evolution of the exciting apparatus. The early high tension generators had certain inherent complications and limitations. The static machine gave an almost ideal discharge as to steadiness but of very limited quantity.

Also, it was often difficult to get it to function. The induction coil required an interrupter to break a direct current and a properly proportioned condenser to get full output. The wave form might be very irregular as may be seen by oscillograms. There was always more or less "inverse," a source of serious trouble in all tube operation.

FIG. 1.



F target of X-ray tube. A narrow beam of rays passes the lead slits and reaches the film on the revolving cylinder. When a synchronous rectifier is used we have four half waves per revolution as shown by the continuous line.

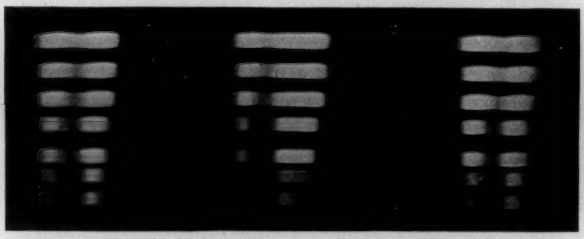
At the instants marked *AD*, etc., there is no tube current and no X-rays. During the time *AB* and again *CD* there is tube current but the voltage is too low to give effective radiation.

When no synchronously driven switch is used the half waves shown as dotted lines are not able to pass through the tube.

The X-ray transformer, developed to operate on alternating current, required a strictly synchronous motor to operate a revolving switch. Such devices were relatively complicated, bulky and heavy and were constructed to deliver enormously more power than could be utilized in practice. Thus a tube may operate on a power intake of 3 k. w., but machines of 10 to 15 k. w. *continuous* rating were supplied, although only a *single* tube was to be operated at one time. Now the output of an X-ray tube is dependent on the current through it and on the voltage drop

between its terminals. The voltage is a much more important factor than the current as the radiation at a given current increases at least in proportion to the *square* of the voltage. During a single set of current changes from no current through all its variation back to no current again there will be, at each instant, some voltage and current, but only when the voltage is high enough

FIG. 2.



A series of exposures using the apparatus of Fig. 1. One exposure has been cut out to shorten the figure. Four exposures result from *one* revolution of the motor.
Note the clear spaces between the dark strips showing that current at low voltage is ineffective. The longest strips were made at 45 k.v. the others at 40, 35, etc., to 15 k. v. An oscillation caused a voltage drop distorting the wave from giving the light areas in the exposed strips.

FIG. 3.

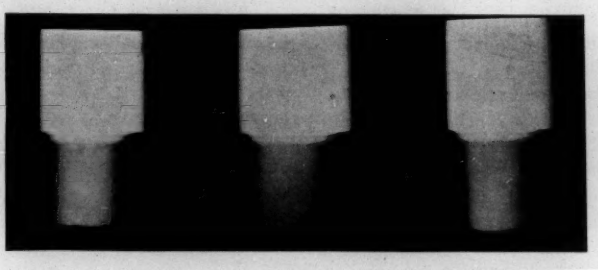
Shows a similar set using a hot cathode tube, self-rectifying. Only two spots per revolution.

for the production of rays able to pass out through the walls of the tube will we get a delivery of X-rays. This is shown by photographing the X-ray delivery on a moving film attached to a cylinder rotated by a synchronous motor and operated on the same circuit as the X-ray transformer. The rays pass through a narrow slit and each area in the photographs shown was exposed 450 times (15 sec.). Note the much greater in-

tensities at the higher voltage *all* other factors, *viz.*, time, current, distance and development being the same. Note also those of a self-rectifying tube, where only two spots appear per revolution.

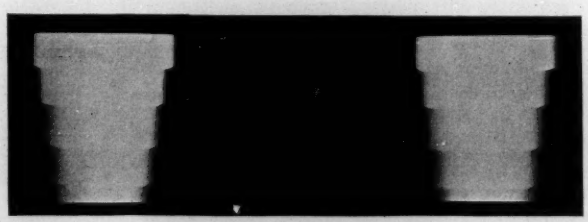
When we introduce aluminum in the path we find much of the radiation sent out during low voltage fails to pass through

FIG. 4.



One half of the slit of Fig. 1 was covered by 4 mm. of aluminum. On a 6" gap only ¼ the time was given to the upper portion in order to nearly equalize the exposures. More of the radiation at the higher gap is able to pass through the aluminum.

FIG. 5.



Reduction by absorption of several millimeters of aluminum. 0, 1, 2, 3, and 4 mm. filters used.

even a thin layer. Clearly the most efficient use of electric energy, *i.e.*, the greatest X-ray delivery for a given heat produced at the target would be when all the current is passed at the same potential, *i.e.*, when the voltage is unfluctuating. The work of Hull showed that 2 M. A. at a constant voltage produced radiation identical in all respects to that given by 3 M. A. sine wave. Appliances to give unfluctuating voltages of 100 k. v. or more are

expensive and will probably not be generally used in practice, but will be of enormous value in research and standardization. And it is not at all unlikely that simpler methods may be found to secure at once the highest voltage and a steady output.

Eighteen years after Röntgen's discovery, or in 1913, began what I would designate as the recent period, due to two remarkable discoveries or developments. One the hot cathode tube by Coolidge, the other diffraction of X-rays and resulting interference phenomena by Laue. The former gave us a tube of stable and reproducible performance, the other not only indicated the nature of X-rays but has proved a powerful tool in their application.

Do not conclude that I wish to imply that nothing was accomplished in preparation for these results in the interim between 1895 and 1913. For, starting with Röntgen's experiments there followed the discovery of radioactivity ultimately resulting in the electron theory of electricity, or perhaps I should say, of matter, and the Coolidge tube may be said to be a most perfect application of these new developments. Machines for rectifying high-tension alternating currents had been perfected by Snook and others so that high-power exciters to operate the powerful new tube were already in use.

The Coolidge tube when the anode is cold, *i.e.*, below a few hundred degrees centigrade, permits current to pass in only one direction, *i.e.*, is self-rectifying. Early in 1917 Doctor Coolidge undertook to develop a tube primarily for army use, utilizing this principle and eliminating the synchronously driven switch. In order to carry away the heat developed at the anode he returned to the use of a tungsten button set in copper and utilized an outside radiator also previously employed with gas tubes. This tube was soon known as the radiator type Coolidge, and was used in the U. S. A. portable and bedside outfits. Although limited to 10 M. A. at 60 k. v., or .6 k. w., its performance marked a new era in medical röntgenology. These tubes are now furnished for 30 M. A. and on account of small size and the simplicity of operation are likely to largely displace the "interrupterless transformer" except for therapy. What the future holds for this field one hardly dares to predict, but surely the end is not yet.

Let us now summarize the main features in the production

and the known properties of X-rays as a basis for the consideration of their applications.

1. They are due to the sudden change in velocity of electrons, *i.e.*, small natural negative charges.

2. They travel in straight lines from the points where the electrons are stopped.

3. Their velocity is probably the same as that of light.

4. They are reflected by atoms in proportion to the atomic weight of the atoms struck.

5. They excite relatively long wave-length radiation known as fluorescent light in a few materials.

6. They tear electrons from atoms in their flight, rendering gases conducting by ionization, and causing photoelectric effects in liquids and solids.

7. They affect photographic emulsions in a manner similar to light.

8. They show diffraction spectra analogous to light when a sufficiently fine atomic lattice is used as a grating.

9. The X-ray spectrum depends on the voltage of tube operation and on the target material. No tube giving homogeneous rays, *i.e.*, of a single wave-length, is possible.

10. The atomic reflection in a body whose atoms are not organized into crystalline structure resembles the scattering of light by fog. That of a crystal is similar to crossed grating spectra.

11. There are discontinuous spectra as well as continuous as is the case with light sources. The bright line visible spectrum of the incandescent gas is shown at *sufficiently high temperature* while the characteristic lines of the target material are only shown in superposition on the continuous spectrum when we use a *voltage* above a *minimum*, characteristic of each target material.

12. The distribution of radiation among various wave-lengths and the total amount of radiation is profoundly modified by the voltage used which determines the electron speed. Voltage is here analogous to temperature in black body radiation.

13. The absorption of materials shows discontinuities intimately connected with their characteristic emission spectra. This also is analogous to light, absorption and emission.

14. The *minimum* wave-length emitted is a function of the *maximum* voltage available.

15. The extremely short waves are less easily absorbed and thus effects produced through thick masses or dense absorbers are due to the shorter waves of the X-ray spectrum.

Aside from their action on living cells, X-ray applications are based on (1) the absorption effect of matter varying with atomic weight and thickness, (2) on diffraction effects.

The radiation received on a photographic plate or a fluorescent screen shows shadows, *i.e.*, areas of reduced brightness on the screen or increased transparency on the plate, resulting from either a density exceeding that of surrounding material or greater thickness or both. In the various applications this *variation of opacity* must be *interpreted* in the light of *acquired experience*. The general theory is approximately as follows:

If Q = radiation per sq. cm. falling on the proximal surface

Q_2 = radiation falling on a photographic plate after passing through a thickness d of homogenous material.

Q_1 = that having passed a thickness, d–h, of the above material and h c.m. of a denser material.

Assume, what is only approximately true, that μ is the absorption coefficient of the main body and μ_1 that of dense region, where $\mu_1 > \mu$.

$$Q_2 = Q_\varepsilon - \mu d$$
$$Q_1 = Q_\varepsilon - \mu(d-h) - \mu_1 h$$
$$Q_2 - Q_1 = Q_\varepsilon - \mu d \left[1 - e^{-(\mu_1 - \mu)h}\right]$$

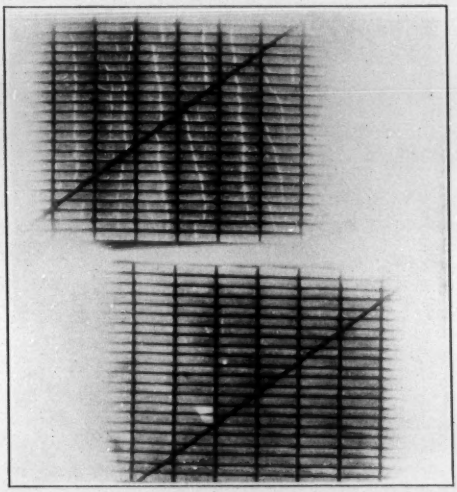
But $Q_2 - Q_1$ must fix the possible contrast between these two areas. This will increase with h, and with the difference in absorption coefficients for the two materials. Since it is also necessary to get some radiation through the body neither d nor μ can be too large.

We must then use sufficiently short wave-lengths to affect the screen or plate, but not so high that μ_1 and μ will approach one another. Thus, if all rays were so penetrating as to go through flesh and bone equally well there would *be no radiograph*, also the bodies must not be too thick or $Q_2 = Q_1 = 0$.

But reference to 10 above shows another very important property that always works against the simple theory, *viz.*, rays do not all go straight through but each atom takes a minute toll and sends these rays in other directions, we do not know whether

or not a single atom scatters in a single direction according to its orientation or not, but it is quite immaterial as there are so many in all sorts of positions that there is a general scattering. There results an undershot radiation, falling where otherwise the radiation is more or less reduced and contrast is lost. In only two ways can this action be overcome, first, by reducing the number of atoms causing scattering by using a diaphragm, thus limiting the amount of material acting, or else by using a device originally due to Bucky and recently developed by Potter.

FIG. 6.

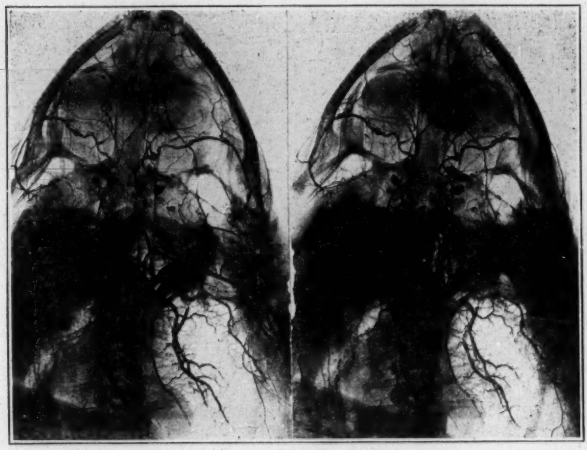


Two storage battery grids. One has several cracks. Some of them not visible in ordinary light.

The fluoroscopic and radiographic action depending on the unequal absorption of X-rays at first found application only in medicine and surgery. The advent of the new tube capable of operation at high power for long periods without damage aroused interest in the radiography of various materials some examples of which may be mentioned here: Defects in small castings; grain of woods; defects in manufacture; pieces of metal in various objects. Fig. 6 shows a defective storage battery grid.

Unfortunately both fluoroscopy and radiography have limitations of several kinds, the small thickness of dense materials radiable, time consumed, cost of apparatus, need for protection of operators, physical limits of vision in fluoroscopy, etc., but in many cases such examinations serve to point out defects due to improper processes or to errors readily avoided. Thus to examine hundreds of thousands of copper commutator bars would

FIG. 7.



Circulatory (arterial) system of a frog. Shown by injecting the arteries and then radiographing.

be prohibitive, but to verify the elimination of gas by boronizing samples is relatively simple.

Where inspection can be made readily by fluoroscopy as in cork, mica, and some small objects, it may easily be made a routine procedure.

Our knowledge of animal and vegetable life and structure may be greatly increased by the use of this aid. Note circulatory system of a common amphibian secured by injection of a fluid carrying barium sulphate (Fig. 7).

Turning now to the second great advance that came in 1913 we may consider briefly the phenomena of diffraction. The plane

diffraction grating is doubtless well known to most of you, but perhaps you have not considered the result of using several such gratings in succession on the same beam of light.

If λ = wave-length

d = grating space.

$$\frac{\lambda}{d} = \sin \theta$$

Since sin θ never exceeds 1,

there is a minor limit to the wave-length for which a given grating may be used.

$d = \frac{\lambda}{\sin \theta}$, *i.e.*, is always greater than λ.

But if θ is to be, say, 30 degrees, sin $\theta = \frac{1}{2}$

Then $d = 2\lambda$, Suppose $\lambda = .00005$, $d = .0001 = 10^{-4}$ and we have need of 10,000 lines per cm.

If $\lambda = 10^{-5}$ $d = 2.10^{-5}$

No. lines per cm. $= \frac{1}{2}\ 10^5 = 5 \times 10^7$

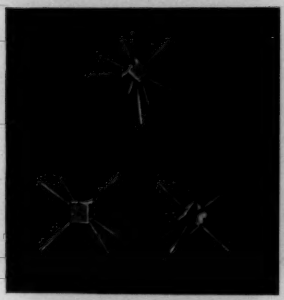
$= 50{,}000{,}000$ or fifty million lines per cm.

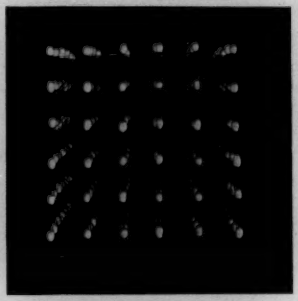
One would hardly try to rule as fine lines as this. But an entirely different course of reasoning had shown that crystals were systematic atomic structures, where the atoms were arranged along straight lines with regular spacing. These again formed sets of parallel planes. The fundamental theory of the optical grating postulates the starting of exactly similar waves from each opening at the same instant or at regular time intervals. Laue conceived the idea that each atom might reflect a minute wave element and the regular arrangement of atoms might constitute a space grating for these very short wave-lengths. A simple way of illustrating this will be to build for you a portion of a crystal enlarged in about the ratio of 50 million to one. Thus you see the uniform spacing along lines and that parallel planes may be passed that contain regular atomic patterns (Fig. 8).

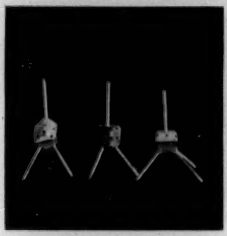
Many applications depend on this diffraction of crystals. For in this way we may ascertain two very important things: (1) The presence of elements by identification of their emission or absorption X-ray spectra, or (2) the presence and type of crystalline structure. The original Laue radiographs may serve in part for (2), but hardly for (1). Reflection methods may serve both ends.

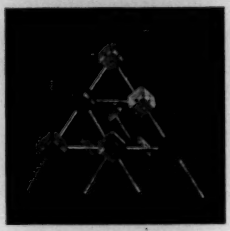
Thus the crystal X-ray spectrometer gave us a knowledge

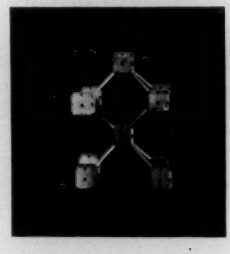
FIG. 8.

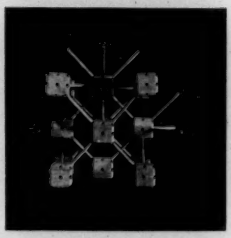












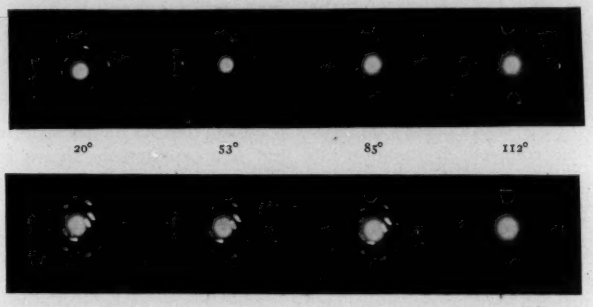
(*a*) Cubical blocks with holes and pegs for use n building crystal models. Holes in the center of each face, the center of each edge and each corner. (*b*) The axial symmetries of such a system, four and three fold. (*c*) Part of a "cubic centered" structure. (*d*) Simple cubic. (*e*) Tetrahedral form of *f*. (*f*) Part of a "face centered cubic" structure.

of the X-ray spectrum and its variation with voltage, then, combined with other methods the rays verified the assumed nature of crystal structure, but even more they told just how the atoms were placed.

True the science of crystallography had been splendidly developed long before X-rays were discovered, but so far as I am aware the exact position of various atoms, and the planes of highest concentration of a given type of atom had not been known. Also, this gives a method for the study of crystals of opaque substances such as metals in a manner not previously possible.

By use of the crystal grating and an ionization chamber the

FIG. 9.



Destruction of crystalline structure of copper sulphate by dehydration.

spectrum of X-ray emission has been studied with reference to the wave-lengths of characteristic spectra and absorption and these results have been verified by photographic methods. An incandescent solid or liquid gives a continuous spectrum varying with the temperature.

A rise in temperature of a hot body adds short waves not present before; increases the intensity of radiation of *all* the wave-lengths present at the lower temperature and shifts the energy peak toward the short wave-lengths. Also an incandescent gas emits a characteristic bright line spectrum that may be superimposed on a continuous spectrum from an incandescent liquid or solid.

Change from temperature, as a controlling factor, to voltage, and we have the same laws in the radiation of X-rays. Further, the characteristic spectra of X-ray emission are relatively very simple and are definitely related to the nature of the atom whose electrical equilibrium has been disturbed at the point of emission. In fact, if we arrange the elements in order by reference to these lines, we shall have with a few slight variations the order of their atomic weight. Here again we break across those accidental boundaries of special sciences to invade the realm of the chemist. We no longer regard the atom as a simple lump of matter but rather as a complex electrical system.

The absorption spectra of X-rays are analogous to those of light. The coefficient of absorption increases with wave-length between two absorption bands. μ/ρ plotted against λ^3 gives a series of straight lines between bands due to the characteristic wave-lengths. Using these results it becomes possible to closely predict how the radiation described by a given spectrum will be distributed in an absorbing medium.

The entire history of an X-ray beam from its inception to its final complete degradation into heat is approximately shown by this chart drawn by Doctor Respondek. The career is surely very interesting and each step might offer a broad field for study.

I have not the time to dwell on that phase of X-ray application, the most widely known, and in some ways the most important, suffice to say the possibilities in the field of medicine are hardly realized to-day, great as we may consider present accomplishments.

Thus has a single epoch-making discovery wrought changes in our lives, our work, our thoughts. How many of the contemporaries of the patient investigators who contributed to the conditions rendering Röntgen's discovery possible realized the importance, or by material support or sympathy encouraged their humble efforts. Yet have these men greatly extended our knowledge with its possibilities for good or ill during a brief century. Sometimes they worked with a definite application in sight, more often were they inspired only by the desire to know more of the world in which man's sojourn is so brief.

That our science and philosophy has been and will still be profoundly modified by these results none will deny, so that these may say as the spirit in Faust,

> "Thus at the ever whirring loom of time I ply,
> And weave for God the garment that thou seest Him by."

REVISION OF SOME OF THE ELECTROMAGNETIC LAWS.

BY

CARL HERING, D.Sc.

Member of the Institute.

THE present celebration of the centennial of the important and fundamental research work of those great pioneers, Ampere and Oersted, is an appropriate occasion to note some of the new phenomena or laws, if any, which may have been found and pointed out in recent times, and more especially to examine more critically the laws of such phenomena as commonly stated in text-books and taught in schools and colleges, to see whether they are still universal laws as far as we now know, or whether any modifications are necessary or desirable in order to make them include modern developments or to make them clearer to the student and more easily understood by him.

When a law is a universal one it means that there are no exceptions, hence if there are exceptions it is not a universal law, and its limitations should then be clearly stated or a new law should be framed which is really universal. If a law is really universal it is possible to maintain with certainty that a proposed device or process which violates it, cannot possibly operate; a proposed perpetual motion is an illustration. If, however, a law is not a universal one, though incorrectly so considered, a proposed new device or process might be unjustly condemned as inoperative, thereby preventing progress in new, untried fields. The writer has met with such cases, in one of which a very useful and well-known law, which was considered to be a universal one, was found to call for a result contrary to the facts; the prediction that a certain new device based on this law would operate was therefore found to be wrong. To teach that a law is universal when it has been shown that it is not, is in the writer's opinion an educational crime, specially against the rising generation which is depended upon to develop new and untrodden fields. If a law is really universal it must apply to all future cases. If we know of no exceptions it is excusable, but after exceptions have been found there is no excuse for continuing to maintain that the law is universal.

Moreover if a law is shown to be incorrectly worded it should be revised so as to be correct. In the writer's opinion this is the physicist's duty to the students he is instructing. In a certain case in the writer's experience a well-known law was relied upon as being correctly stated, and much money and time were spent on a device which would have operated had this law been stated correctly, but the device failed completely due to the law having been incorrectly worded.

In another case the laws in text-books were interpreted by physicists to strenuously deny the existence of certain forces, but the writer found that the results of the actions of such forces existed in practice, and therefore required an explanation for their existence. An adherent of the older law made an attempt to explain the result by the aid of hydraulic forces, but the writer believes it can be shown that the text-book law originally relied upon, or as generally interpreted, is not sufficiently comprehensive in scope, and that a new and broader law can and should be framed which applies correctly to all observed facts, and shows that the forces heretofore denied, really exist.

But even if it is possible to explain the existence of some new observed facts in a round-about, cumbersome, complicated way by means of the older laws of our grandfathers, the writer maintains that it is our duty to the student and to the investigator in new and untrodden fields who is relied upon for new developments, to teach him simpler and broader laws which apply more directly, if such new laws can be framed and are correct.

LIKE CURRENTS ATTRACT.

An old and well-known law, given in every text-book on electricity, is that "like currents attract and unlike repel." This law is not correct as stated. If it were it would necessarily have to follow that the current density in a conductor would have to be greater near the centre than near the periphery, as a current can be considered as made up on a large number of filamentary parallel currents which would attract each other toward the centre. Yet we know that this non-uniform current density does not occur. Or a current from a flat anode to a flat cathode in an electroplating bath would have to cause a denser deposit in the middle of the cathode, which we also know is not the case. Moreover if this law were true the pinch effect mentioned below would not exist, yet we

know it does. Furthermore, two parallel cathode rays passing in the same direction in a vacuum tube will be found to repel each other, which they should if they consist of like charges moving in neighboring paths; this shows directly that like currents really repel each other, when there are no conductors.

The change which should be made in this law to make it apply correctly is to state that these attracting and repelling forces act on the *conductor*, that is, on the material of the conductor, and not on the currents *per se*.[1] The pinch effect shows conclusively that it is the material of the conductor and not the current *per se*, which is moved to the centre by this force. In most cases this distinction between the currents and the conductors is of no consequence, but there are cases in which it is of prime importance, and a law to be universal must include all cases. This distinction is also of interest because an analogous one must also be made in electromagnetic induction, as will be described below, and perhaps in a third case also.

These forces between neighboring current-carrying conductors may be explained as being due to the action of the magnetic flux which encircles them, but it should be noted that this flux acts chiefly on the conductor and not merely on the currents.[2] If it acted chiefly or entirely on the currents it would follow that in the case of two closely adjacent conductors and a constant, direct current, one-half of each conductor would have more current flowing through it than the other half, which it is believed is not the case, except to the slight extent due to the Hall effect.

THE PINCH EFFECT.

Some fourteen years ago the writer, relying on the correctness of the older law, concluded that any metallic conductor could be kept melted in an open channel by simply passing a sufficiently large current through it. He found, however,[3] that this was decidedly not the case, as a sharp limit to the current was reached at which the liquid conductor contracted at one point (always the point of minimum cross section) forming a V-shaped valley which

[1] Maxwell's Treatise, vol. ii, art. 501.

[2] The Hall effect, the existence of which Maxwell denies (Sec. 501), shows that it acts on the currents also, it seems to act in this way when the conductors are not free to move. A definition is given in Northrup's "Laws of Physical Science," p. 159.

[3] *Trans. Amer. Electrochem. Soc.*, vol. 11. 1907, p. 329; also vol. 15, 1919, p. 255.

generally descended quickly all the way to the bottom of the channel, which in this case was about six inches deep and contained molten iron. This of course broke the circuit; the current having ceased, the molten metal flowed together again and was immediately parted again, spitting forth globules of molten metal as from a miniature volcano. Fig. 1 shows about how it appeared just prior to a rupture, E, E being the solid electrodes.

FIG. 1.

The appearance of this V-shaped depression ending in a complete rupture was as though a hugh invisible pinch cock was severing the liquid column as it does when in a rubber tube, and for this reason the writer colloquially gave the phenomenon the name "pinch effect," by which it has since become generally known here and abroad. The term is not a misnomer, as has been alleged,[4] as it describes better than any other one word could do, the appearance of the phenomenon as it is generally seen to occur in open channels.

It can be explained either by saying that the radial contraction of the encircling flux crushes the yielding liquid conductor to the point of severing it; or that the filamentary conductors carrying like currents, attract each other to the vanishing point; the latter would not be true if this electromagnetic force acted on the currents as the older law states, as distinguished from the material of the conductor.

This force has been termed an internal one in order to distinguish it from the forces acting on a conductor from something external to it, like a second neighboring conductor or a magnet, which latter kind of forces, as observed by Ampere, Oersted and others, are elaborately described and discussed in text-books, to the almost complete exclusion of others. To the student this crushing force may be explained as being apparently caused by the contraction of the well-known external flux surrounding it; the internal flux is not so well understood. To call it the "self-crushing" force would seem to be more appropriate and more self-explanatory. The intensity of the flux at any point inside or outside of a conductor, sup-

[4] This Journal, Dec., 1920, p. 833.

posedly represents the *resultant* intensity, at that point, of the flux as a *whole*, inside and outside; hence both contribute to this crushing force. It is true, however, that in the resulting contraction of the conductor only the flux which was inside is cut, and therefore that alone need be considered in quantitative mathematical deductions.

It may be of interest to add here that in the C.G.S. system the writer has found [5] that the quantitative relation of this force to the current and to the circular section when the conductor is far removed from all flux foreign to it, is a unit relation, $P = I^2/S$ in which P is the pressure at the centre in dynes per sq. cm., I is the current in C.G.S units, and the cross section S is in sq. cm. It is therefore not a direct function of the current density alone.

This contraction is accompanied by a very marked movement of the liquid conductor in the direction of the axis as shown in Fig. 1. This was at first thought to be a hydraulic resultant of the radial pressure. It will be shown below that there are good reasons to believe that there exists also a self-produced stretching force. This contracting force is also influenced very greatly by neighboring external currents and magnets. Electric furnaces in which these forces and others are relied upon to expel the molten metal from resistors in which the heat is developed in the metal itself [6] are in use in large numbers.[7] Fig. 9, described below, shows diagrammatically one of the earlier types.

MAXWELL'S LAW OF INDUCTION.

Maxwell's well-known and much-used law of electromagnetic induction, as stated in most and probably all text-books, is based on the altering of the amount of magnetic flux in an electric "circuit" (Maxwell's own term), that is, on the linking and unlinking of the magnetic and electric circuits. This law is the basis of the calculation of all of the usual electric generators, motors and transformers, and seems to be considered as the fundamental, universal, law of induction.[8] It was therefore supposed that it could be relied upon as being a universal law, that is, without any exception.

[5] *Metallurg. and Chem. Eng.*, vol. 9, Feb., 1911, p. 86.

[6] This Journal July, 1911, p. 64.

[7] This Journal Oct., 1920, pp. 499-500.

[8] Maxwell, Sec. 541, says we can "enunciate completely the true law of magneto-electric induction" in this way.

It was thus relied upon by the writer more than a dozen years ago, in devising a new induction apparatus which would have had some very valuable properties, but from previous experience with the incorrect statements of such laws in text-books, it was thought best to test this law first with a simple crucial experiment. This test [9] showed that any or all of the flux included in a closed electric circuit could be removed (and replaced) without inducing any electromotive force whatsoever, and of course, without opening the

FIG. 2.

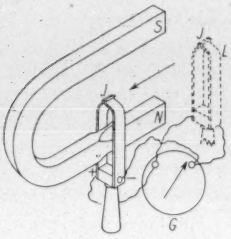
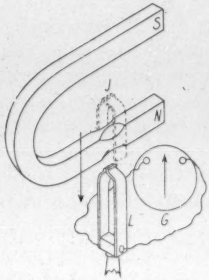


FIG. 3.



circuit. Maxwell's own statement of his law,[10] as also the various versions of it by others, when read on this experiment require that induction must take place. Hence this experiment violates his law, and is therefore an exception; and the law is therefore not a universal one, and can no longer be relied upon as such. This is believed to have been the first demonstration of an exception to this law.

Figs. 2 and 3, taken from the original paper, show that when the circuit or loop L was linked with the flux in the usual way, as shown in Fig. 2, there resulted the expected induction, as shown by the deflection in the galvanometer G. But when unlinked in the manner shown in Fig. 3, there was not the slightest induction; the circuit, of course, was closed all the time. The circuit cut the flux but the conductor did not.

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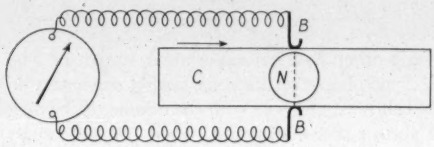
[9] *Trans. Amer. Inst. Elec. Eng.*, vol. 27, part 2, 1908, p. 1341. The original, crude apparatus was deposited, by request, in the museum of the Franklin Institute.

[10] Vol. 2, sec. 531 of his well-known Treatise. Also Northrup's "Laws of Physical Science," p. 145.

At the writer's suggestion C. P. Steinmetz then formulated a new law,[11] which it seems can be relied upon as being universal, and it is probably the first time such a law which is really universal was ever formulated.

The point brought to light by this experiment is analogous to the other case cited above, that it is again very necessary to make a distinction between the conductor itself and the circuit *per se*. Such a distinction was not made in this case by Maxwell, who refers only to the "circuit" as he himself calls it. As magnetic flux necessarily forms a closed circuit which cannot possibly be "opened" like an electric circuit, it follows that in "altering" (to use Maxwell's

FIG. 4.



own term) the amount of flux in any closed electric circuit, the flux must "cut" across the circuit, to use Faraday's term. The distinguishing feature in this experiment is that the conductor itself does not cut across the magnetic flux, although the "circuit" does.

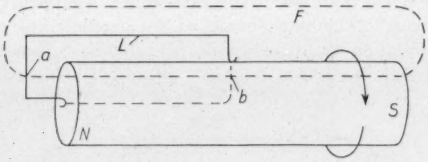
If Faraday had made one more variation of one of his classical experiments than he did, he would have noticed this distinction, and his follower Maxwell would presumably have modified his own statement accordingly. In this experiment by Faraday,[12] shown in Fig. 4, a copper strip *C* was drawn across the face of the pole of a stationary magnet *N*; two fixed brushes *B B* connected to a galvanometer, completed the closed electric "circuit" across a part of the strip, as shown by the dotted line which the present writer has added. On moving the strip he found a current was induced. Had he moved the magnet while the strip and the brushes were at rest, he would also have obtained a current, and it would have been an exact demonstration of Maxwell's statement of the law, as the

[11] *Trans. Am. Inst. Elec. Eng.*, vol. 27, part 2, 1908, p. 1362.

[12] Faraday's "Researches," 1831. Fig. 16. Plate III, described in paragraph 101, and re-produced in an article by the writer on "A New Fractor in Induction; the 'Loop' vs. the 'Cutting Lines of Force' Laws," in the *Elec. World*, vol. 51, March 14, 1908, p. 559.

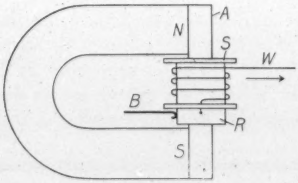
amount of flux within the "circuit" would have been "altered." But if he had in this latter variation, moved both the magnet and the strip together, Maxwell's law should have applied as before, as the flux within the circuit was altered precisely as before, but there would not have been the slightest induction, as the material of the conductor did not cut across the flux although the circuit did.

FIG. 5.



Faraday's other classical experiment shown in Fig. 5, with a magnet $N\,S$ revolving on its axis, and a stationary loop L connecting the centre of one pole with the middle of the magnet, would also have shown this distinction, when properly analyzed. The electric circuit is here shown as it is completed through the magnet; the same flux F is necessarily cut twice by the circuit, in its two opposite directions, at a and at b, and would therefore produce no resulting induction were it not for the fact that in one of these

FIG. 6.



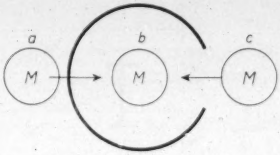
transits across the flux the conductor itself does not cut the flux, though the circuit does. This is true whether the flux revolves with the magnet or is supposed to be stationary in space.

There is another striking experiment shown in Fig. 6, which also violates the Maxwell law, much to the surprise of some who tried it. If a few turns of a coil of flexible wire be wound on a spool S, revolvable over an iron core axis A, there will of course be induction when the poles of a magnet are brought to the ends of

the iron core, as the flux and the coil will thereby become linked. But if now the wire W be pulled off tangentially to the coil, the spool revolving on its axis, the contact with the inner end being made by means of a slip ring R and a stationary brush B, there will not be the slightest induction although the flux and the circuit have thereby been completely unlinked, while the circuit remained closed by the measuring instrument. No part of the conductor has cut any of the flux.

Still another experiment, but one which is difficult to carry out, is to form a nearly closed circuit like the letter C, Fig. 7; then by passing the flux from a magnet M across the conductor from the

FIG. 7.



position a to b a difference of potential should be found to have been produced at the two open terminals of the circuit; this will probably not be denied; the flux and the nearly closed circuit have been linked thereby. But if the same flux were passed through the open part of the circuit from c to b, being brought to the same position b within the circuit as before, therefore producing the same ultimate linkages as before, it will no doubt be admitted that there would be no induction. In the one case the flux was cut by the conductor itself, and in the second case it was not. A unipolar generator might be constructed on this principle if the poles of a revolving magnet be made annular and moved so that the flux enters through the opening of the C and leaves across the conductor, the circuit being always closed across the opening by brushes touching the circular core.

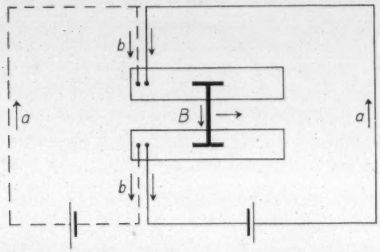
These experiments also show, what Maxwell's law fails to show, that the actual induction takes place at, and only at, that part of the conductor which cuts across the flux, and not in general all around the circuit as Maxwell's words, "an electromotive force acts round the circuit," have been interpreted to mean; the rest of the circuit is a mere dead conductor, as far as any induction is con-

cerned, as was shown experimentally by the writer many years ago.[13]

THE STRETCH EFFECT.

The writer's researches with the pinch effect a number of years ago led him to the belief that there should also exist a complementary force axial to the conductor and also produced by the current in the conductor itself as distinguished from being caused by external currents or magnets. Just as the pinch effect tends to crush the conductor radially reducing its cross section, so this other force tends to stretch the conductor axially, thereby tending to in-

FIG. 8.



crease its length, somewhat like a spiral spring which had been compressed axially, except that this stretching force should theoretically continue without limit as the conductor yields to it, and in fact it presumably even increases if this stretching diminishes the cross section (as it sometimes does; see Fig. 1), just as the pinch effect increases as its effect on reducing the cross section increases. The name of "stretch effect" was given it, and the reasons for its existence were described by the writer at that time.[14] Some experiments were there described, the movements in which were predicted on the basis that such a stretching force exists, but were contrary to what they should be according to the older theories.

One of these, a modified form of the well-known Ampere mercury trough experiment, is reproduced in Fig. 8; the dotted circuit shows the way the experiment is usually carried out. One

[13] "The So-called 'Dead Wire' and Gramme Armatures." *Elec. and Elec. Eng.*, vol. 6, May, 1887, p. 171.

[14] This Journal, Jan., 1911, p. 73.

of the usual explanations is that the movement of the floating bridge piece B to the right is due to the fact that every circuit tends to expand. Another is that the current in B, being opposite in direction to that at a, they repel each other; an inquiring mind, however, will ask why B is then not attracted to the left by the like currents at b and b which are much nearer to it.

The writer's explanation is that every circuit tends to lengthen or stretch itself, as that increases the amount of flux (thereby generating a counter e.m.f.) in proportion to its increase in length, if far removed from all other circuits, and if the stretching does not decrease the cross section.[15] The only part which has a freedom of motion lengthwise is the part in the mercury troughs, which part therefore lengthens. As the counter e.m.f. developed thereby is due to the flux which has been added by this increase in length, the real seat and origin of this force should be attributed to this tendency to stretch and not primarily to the interaction of the two conductors at right angles to each other; the latter is really a resultant secondary force.

To show that both of the older explanations are in error, the writer reversed the battery loop as shown in full lines in Fig. 8, and found that the direction of motion of B was, as predicted, the same as before, when it should have reversed according to both of the older theories. The area embraced by the circuit now actually contracts, and the stretching force is greater than the combined attraction and repulsion of b b and a. The return circuits in this test must not be too near the troughs.

It is thought that both the crushing and stretching are merely different manifestations of the same prime cause, namely the flux surrounding the conductor and produced by its own current. This encircling flux tends to contract around the conductor, thereby tending to crush it, and the parallel elements of this flux in planes perpendicular to the conductor, tend to repel each other, thereby tending to stretch the conductor. Both motions are very pro-

[15] In a paper on "Ampere-Centimeter, a Measure of Electromagnetism," read by the writer before the Electrical Section of the Franklin Institute in 1892, published in this Journal, vol. 134, p. 69, it is shown that for a filamentary conductor (having no appreciable thickness) and removed from all external currents or magnets, the amount of flux encircling it per ampere per unit of length is constant. Hence for a material conductor the flux increases in proportion to the length, if not influenced by other external conductors or magnets. Amount of flux is the same kind of a physical quantity as current x length.

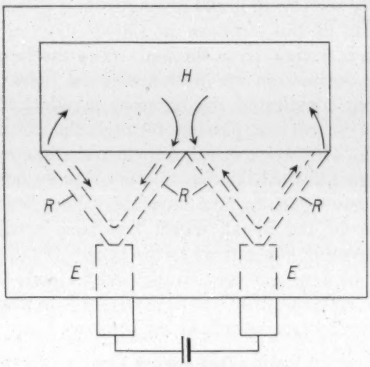
nounced when the current densities are great, and if they are the same phenomena it may not be safe at present to say which is the primary one and which the secondary or resultant one. Reasons will be given below why it is thought by the writer that the prime cause of both is the same, and that either or both movements will result depending upon which are mechanically possible from the nature of the conductor and its surroundings. For instance, in a circumferentially enclosed channel immersed deeply below the surface of a bath of metal, in which rupture by the radial contraction is prevented by the hydraulic pressure, the axial movement (stretch effect) is very strong and decided; while in a short open channel with solid walls at the ends limiting the stretching, the transverse crushing (pinch effect) is most marked. But either one could explain both movements if the other is assumed to be a hydraulic resultant.

No quantitative relations have as yet been deduced for this stretching force, but it is likely that it increases with the square of the current, and is some inverse function of the cross section. It could be stated either as a force or (as in the case of the pinch effect) as a pressure, and is probably in its simplest form for a circular section; the formula for the pinch effect becomes highly complicated for any other form of section. It must also be assumed that there are no fluxes foreign to that of the conductor itself, as such foreign fluxes no doubt have very pronounced effects. The stretching force is assumed to be due to the mutual repulsion of the disks of flux around a conductor, and presumably the flux in the interior also contributes its share. The stretching may sometimes give rise to a contraction of the cross section, as in a curved band of mercury on a flat table, resulting in an ultimate rupture at the weakest point where the stretching force becomes greatest. It is even conceivable that this stretching force might become so great that a straight, though very flexible, conductor like a liquid, might double up on itself somewhat like the letter S, which gives a greater length between two stationary points; we know that a long spiral spring under compression tends to assume such shapes if thereby it can lengthen itself.

But some physicists strenuously maintain that all electromagnetic forces acting on a current-carrying conductor, whether produced in the conductor itself or by neighboring conductors or magnets, must of necessity always be perpendicular to the axis of

the conductor, and can therefore never have a resultant in the direction of the axis.[16] Over a dozen years ago when the writer was making researches in which such axial movements of the conductor were very pronounced, it was alleged by others that axial electromagnetic forces were not known to the art, and could not possibly exist. But the observed results required an explanation.

FIG. 9.



THE CORNER EFFECT.

At that same time the writer noticed that in an open channel containing mercury and making a right angle corner, there was a very marked mechanical agitation at the corner, and with a current that was apparently not great enough to disturb the metal in the two channels forming the corner; he therefore called it the "corner effect," and concluded it was due to the mutual electromagnetic effects of two neighboring current-carrying conductors inclined to each other. It was at that time explained to others, including G. H. Clamer and the writer's assistant, James Wyatt, of the Ajax Metal Company, and together we then constructed a furnace at those works designed by the writer, based on the interaction of two

[16] Maxwell's Treatise, vol. 2, art. 505-508. Also Northrup's "Laws of Physical Science," p. 152, par. 3: "If a wire carries a current no external magnetic force can so act upon the wire as to tend to make it move in the direction of its length." Presumably no distinction was intended between external and internal magnetic forces.

conductors inclined to each other, with the object of producing a unidirectional flow through the resistors. The result was as predicted by the theory. A number of years later this same force was given by others [17] the name "motor effect," which, however, is not a proper distinguishing name, as all of these several forces which produce motion are equally well entitled to this name; its original colloquial name "corner effect" has at least the redeeming feature of more clearly specifying it and distinguishing it from the others.

The action in this furnace is shown diagrammatically in Fig. 9, which is a view from the top. *H* is the hearth of liquid metal. Near the bottom are four horizontal holes *R* the liquid metal in which constituted the resistors in which the heat was developed by the current passing through them from the solid electrodes *EE*. The above mentioned electromagnetic forces were relied upon to expel the heated metal very rapidly into the hearth, cooler metal flowing in to take its place. The directions of the observed flow of the metal, which had been predicted by the writer, are shown by the arrows in the hearth *H;* this flow in the directions of the axes was very strong and decided; the directions of the electric currents (for one half wave of an alternating current) are shown by arrows next to the resistors *R*.

AXIAL FORCES.

It was again alleged by physicists that none but perpendicular forces can exist, and an effort was made [18] to show that the axial flow was due to a resultant hydraulic force. When two conductors carrying like currents are parallel to each other they will attract each other, but it has been denied that when they are inclined to each other and are mounted so that they are free to move only in the direction of their axes, this same attracting force has any tendency to move them lengthwise as they would if they were magnets.

The explanation originally offered by the writer is borne out in Ganot's well-known and generally reliable "Physics," [19] in which the resultant electromagnetic force between two current-carrying conductors at right angles to each other, is shown to be along a

[17] This Journal, Oct., 1920, p. 491, and Dec., 1920, p. 817.

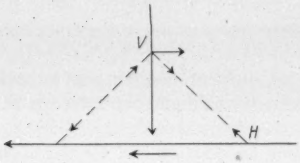
[18] This Journal, Dec., 1920, p. 817. Also E. F. Northrup's "Laws of Physical Science," p. 143 (published many years later and after the writer had explained the observed results to him).

[19] Eighth edition, p. 740, art. 835; or twelfth edition, p. 811, art. 862.

diagonal line across the corner as in Fig. 10. It necessarily follows from this that there is a component of this force in the direction of the axis of each of the conductors, hence an axial force. And as this referred to wires there could not have been any hydraulic action.

But there is also a direct demonstration. In the old and classic experiment referred to in Ganot by this diagram, Fig. 10, the apparatus for which probably exists in most well-equipped physical lecture rooms, a vertical conductor V was mounted so that it could

FIG. 10.



move only parallel to itself, hence only by a force perpendicular to it; the other conductor H beneath it was horizontal and stationary. When current was passed through both, the vertical one moved parallel to itself in the plane of H and V, thereby showing the accepted perpendicular force. This experiment is thought to be attributed to Faraday.

It seems strange, however, that during the nearly hundred years since, it has not seemed to have occured to any one that as this force was relative to the conductors it must necessarily follow [20] that if the same apparatus were reversed so that the vertical conductor was stationary and the horizontal one so mounted that it could move only in the direction of its axis, it would so move, thereby showing the existence of the axial force heretofore so strenuously denied by some physicists. There seems to be no apparent reason why this should be an exception to Newton's third law. This reversal was tried by the writer and shown to others; the action was as predicted.

The well-known and classical Ampere trough experiment, Fig. 8, already referred to, affords another and in some respects better way of demonstrating this. If this apparatus be reversed in

[20] Newton's third law of motion, "To every action there is always an equal and contrary reaction." Northrup's "Laws of Physical Science," p. 3.

the sense that the bridge wire is now made the stationary part and the whole of the rest of the circuit is mounted so that it can move parallel to the axis of the troughs, it should move in that direction according to Newton's third law, thereby again showing the existence of the axial force denied by physicists. And as the mercury could be replaced by solid wires with sliding contacts, the action cannot be hydraulic.

These experiments again show, analogously to the others, that the action is on the material of the conductors and not on the currents *per se* nor on the flux. The flux at a corner is distorted and this gives rise to forces, but these act to move the conductors and not merely the flux.

REVOLVING A CONDUCTOR AROUND ITS AXIS.

If this same principle of reversing an experiment by making the stationary parts movable and the movable parts stationary be applied to a curious experiment described by E. F. Northrup, it could be shown that an odd internal electromagnetic force exists which tends to revolve a conductor continuously around its own axis. Few if any would have suspected the existence of such an odd force; nor is this a force perpendicular to the conductor, in the sense of tending to move the whole conductor parallel to itself. It is dangerous to claim that forces differing from those known to Maxwell cannot possibly exist. According to Maxwell the Hall effect could not exist, yet it does.

In this experiment of Northrup's [21] a magnet with like poles at the ends, and the other pole in the middle, is mounted horizontally so that it can revolve in a horizontal plane around a vertical axis. It is placed in a cylindrical jar slightly larger in diameter than the length of the magnet. The jar is filled with a good conducting electrolyte. When a current is passed lengthwise through the jar the magnet will revolve, hence it would have to follow from Newton's third law that if this magnet were stationary the conductor (the liquid) would have to revolve around its own axis. No hydraulic force is involved. It is based on the magnetic flux in the interior of a conductor.

The present writer has also shown [22] how this same device

[21] *Physical Review*, vol. xxiv, no. 6, June, 1907, p. 480.

[22] "Direct Currents in Electrolytes without Electrodes." *Trans. Amer. Electrochem. Soc.*, vol. 13, 1908, p. 273. The Northrup apparatus is illustrated in this paper.

could be made to generate a continuous direct current in an electrolyte without the aid of electrodes, which was thought by some to be impossible. This could be done by forcing the magnet to rotate, which would generate a current in the interior of a circuit consisting entirely of an electrolyte; the magnet can be insulated from the electrolyte. It is probably not adapted for practical application.

MOVING FLUX.

It is admitted that when a magnet is moved about irregularly in space the flux moves with it, but it is maintained by some that when the magnet is revolved around its own axis, is a perfect cylinder, and is uniformly magnetized, it forms an exception as the flux is then claimed to remain fixed in space, in the sense that there would be no induction in a stationary wire radial to the conductor; in Fig. 5 the induction then would be at *b* and not at *a*. Similarly if a current-carrying conductor be moved axially, its encircling flux would not move with it, and would not cause induction in a stationary wire radial to it.

It is difficult to determine this experimentally because any closed circuit would be cut a second time by the same flux reversed. But by using mercury drops to carry the induced charges from such a conductor to a condenser, during the second transit through the flux, it would seem to be possible to determine it. In the writer's experiment based on Fig. 10, in which there was an axial motion of the wire *H*, a counter e.m.f. was presumably induced in the vertical wire *V* which multiplied by the current represented the kinetic energy which was being set free. It would seem that this counter e.m.f. was induced by the flux which encircles the moving wire *H* and cuts the vertical wire *V*. If so, the flux moves with the wire.

It would assist in analyzing some of these odd cases, to know whether the flux moves with its material source or not. If it does then it must move with a conductor which moves axially.

GENERAL CONCLUSIONS.

The general conclusion, to be drawn from these observed results in the several cases described above, is that some revisions are necessary in several of our laws of electromagnetism; this seems preferable to the more or less desperate attempts which have been made to put the older laws through what might well be called con-

tortions, in order to try to make them still fit these exceptions. It is our duty to the student and coming generation to make these laws universal, as far as we know now, therefore making them apply to future cases as well, and to state them so that they not only can be easily understood, interpreted and relied upon, but also that they cannot be misunderstood. The engineer, who applies these laws, looks to the physicist to state them clearly and correctly.

One of the points brought out by these observed results is, as was stated, that a clearer distinction is necessary between the material conductor and the more subtle circuit, current, and flux. The other is that, in the opinion of the writer, it seems possible to frame a more general law, which as far as is now known seems to cover all the known cases, old and new, of the actions of electromagnetic forces on conductors. The writer ventures to suggest that such a law could be based on the following considerations.

There is a general principle in mechanics [23] that in any system such motions will tend to take place as will reduce the potential energy of the system. What particular motions will actually take place depends of course on the mechanical freedom which the parts may have. A weight will reduce its potential energy by falling directly to earth, or along an inclined plane if such a plane interferes with the vertical fall, or along a curve if it is mounted as a pendulum; water will flow down hill through tortuous paths, including a syphon; a body moving rapidly enough eastward could decrease the potential energy of the earth by moving rapidly away from it against gravity, owing to centrifugal force. Although gravity acts only vertically, the motions to reduce this kind of potential energy may be various. The potential energy which is thereby lost is converted into kinetic energy and appears as work done by the system. If during these motions this amount of kinetic energy is being continuously replaced to the system from some external source, the motion will continue even though there is then no further reduction of potential energy thereby. Thus from an elevated water-tank the water will flow downward to reduce its potential energy, even though the tank is being kept full by a pump whereby the potential energy of the system is maintained constant.

This general law should apply equally well to a system con-

[23] J. J. Thomson, "Elements of Electricity and Magnetism," p. 82, reprinted in Northrup's "Laws of Physical Science," p. 7.

sisting of a current-carrying electric circuit, the current being considered merely as that which produces the potential energy. If so, then it follows that any motions of the conductors will tend to take place which will tend to reduce what might properly be called the potential energy of the circuit; it seems unwarranted, therefore to limit these motions to any particular kinds or directions, provided only that they are such as would, if they took place, reduce the potential energy of the whole circuit. A liquid conductor will naturally respond more readily to some of these forces than a solid one, and secondary hydraulic forces might sometimes be developed in them, as in Fig. 11 described below. In an electric circuit any and every motion which changes potential into kinetic energy it is believed must necessarily generate a counter e.m.f. which if multiplied by the current flowing (if in phase) is the kinetic energy. Hence in general it seems that any motion which generates a counter e.m.f. will take place if the conditions of freedom exist; there should be no further restrictions as to any particular directions. If this counter e.m.f. is then continuously balanced by increasing the direct e.m.f. of the circuit by an equal amount, the same motion will continue if its freedom is continued, without a further reduction of the potential energy of the system. A circuit with a motor or a furnace,[24] like that in Fig. 9, is an illustration.

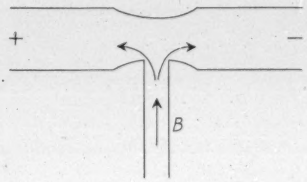
Such a general law would seem to explain and justify all the various observed motions be they perpendicular, inclined, axial (longitudinal, therefore including the actions of neighboring conductors and the corner effect), radially contracting (the pinch effect), longitudinally expanding (stretch effect), a continuous motion which produces no ultimate deformation of the circuit (though producing a counter e.m.f.), and no doubt any other motions not yet observed.

When two neighboring conductors with like currents move toward each other some flux is cut, producing a counter e.m.f.; the same when they move away from each other due to their repulsion. When the pinch effect acts, the internal flux is cut, producing a counter e.m.f. When a conductor elongates itself, additional flux is added to the system, which produces a counter e.m.f. When a

[24] In one of the writer's electric resistance furnaces, in which hundreds of pounds of molten brass were continuously being set into rapid motion lengthwise to the axis of the channels, this counter e.m.f. was found to be about 50 per cent. of the total, and represented nearly 50 kilowatts.

conductor like H in Fig. 10 moves axially near another, V, making an angle with it, flux is cut, producing a counter e.m.f. It may not always be easy to explain how the flux is cut, but the very fact that the potential energy of the circuit produces motion and therefore converts some of its potential energy into kinetic, seems to mean that a counter e.m.f. must be produced thereby. A movement toward or away from a denser field of flux must cut some flux. It seems even that a motion of one part may take place without generating any counter e.m.f. in that part, if by such motion changes of flux can take palce which generate a counter e.m.f. in another and

FIG. 11.



stationary part of the same circuit. The movement of the bridge piece B in Fig. 8 seems to be an illustration, as the seat of the counter e.m.f. must be in the lengthened parts of the mercury troughs which are stationary, not in the moving part B. In general it seems unsafe to restrict these self-produced motions any more than that they must reduce the potential energy of the circuit, which it seems can be done only by producing a counter e.m.f. in some part of the circuit.

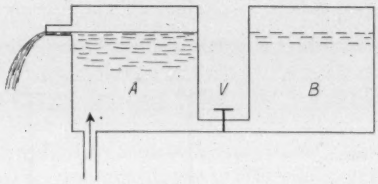
In liquid conductors there are of course likely to be some evidently secondary motions which are purely hydraulic. For instance, in a tube or channel having a branch B, as shown in Fig. 11, both the tube and the branch being in a horizontal plane, there will be a decided motion in the branch B, due to the suction caused by the pinch or stretch effect in the main tube. The fact that the liquid while it is still in the branch is not a part of the conductor, shows that the motion is due to hydraulic forces. Even when a current does flow through B also, there will be some purely hydraulic forces when the radial contraction in the main tube is greater or less than the axial pressure in the branch B.

In the application of this general law to a current-carrying elec-

tric circuit, there is, at first sight, an apparent contradiction in some cases, in that the circuit as a whole may have *greater* potential energy instead of less, after the motion has taken palce, than it had before; this may be the reason why this general law has not before been applied to electric circuits to explain the observed motions. That this is not really a contradiction but only apparently so, is perhaps best shown by the following mechanical analogy:

In Fig. 12 let A be a tank which is constantly being kept full to its overflowing level by a pump, that is, by kinetic energy. The

FIG. 12.



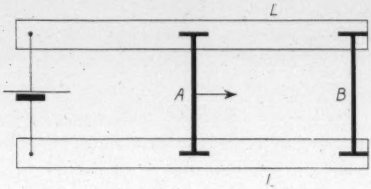
water in it may correctly be said to have the same potential energy as though in a static condition, that is, as though both the supply and the overflow ceased. Hence when a valve V is opened, it is the tendency to reduce its potential energy that causes the water to flow into the second tank B. There will be a temporary drop of the water level in A, but if during this flow the pump keeps supplying water continuously to the tank A, the tank B will ultimately be filled to the same overflow level as in A originally. The final potential energy of both the tanks together will then be greater than it was originally in A alone, yet the *cause* of the flow into the tank B was nevertheless the tendency of the potential energy of the tank A to reduce itself; the general law of mechanics has not been contradicted; the additional potential energy of the tank B has been supplied by the pump.

Similarly, in a current-carrying electric circuit, the potential energy (the magnetic flux) is being maintained kinetically by the current, yet it can correctly be considered as the true potential energy of the circuit. If now in the Ampere trough, Fig. 13, the bridge piece is originally at A and is permitted to move by itself to B, it is true that the potential energy (approximately proportional to the areas of the loops) will have been increased thereby, but this does not contradict the general law any more than in the above

water analogy. While A was moving to B a counter e.m.f. was being induced due to the creation of the new flux in the lengthened parts of the circuit $L\,L$; this temporarily reduced the current by opposing the direct e.m.f. (a constant potential source being assumed) and therefore temporarily the potential energy (the flux) is reduced by an amount equal to the kinetic energy consumed in moving the bridge A; momentarily therefore the original potential energy is reduced by a conversion of a part of it into kinetic energy, precisely as in the water tank analogy.

But when the motion ceases, the counter e.m.f. also ceases, and the current again rises to its original amount, it being assumed of

FIG. 13.



course that the added resistance of the increased length $L\,L$ is negligible as compared with that of the rest of the circuit. In this building up again to its original amount, the current has thereby supplied the additional potential energy of the lengthened circuit, and this additional energy will of course be exactly equal to that which would be required to start an equal current in the added parts $L\,L$, that is, to overcome the self-inductance of those parts; this energy is supplied by the source and not by the original potential energy. The fact that the final potential energy may be greater than the original, therefore does not contradict the general law of mechanics as applied to electric circuits any more than it did in the above mechanical analogy. The confusion is due to the fact that (like in the water analogy) a true potential energy is being maintained kinetically by a source which may add new potential energy to the system. The true *cause* of the motion of a circuit is still in accordance with this general law of mechanics.

The writer believes his statement is incontestable that in the case of electric circuits the self-conversion of the potential energy (flux) into kinetic (mechanical movement) is and must be charac-

terized by the production of a counter e.m.f. by that motion. Hence he believes that it is a general law that a current-carrying circuit will tend to produce *any* and *only* such motions of its conductors as will produce a counter e.m.f. somewhere in that circuit, though as explained above, not necessarily in the moving part itself.

In the particular experiment described by Maxwell, on which he based his generalized statement that no axial force can exist, an axial motion could not have produced any counter e.m.f., hence should not have existed according to the present writer's statement; but in other forms of experiments, as in some of those described above, in which an axial movement can produce a counter e.m.f., the existence of the axial force is evidenced.

A thorough experimental analysis of the various forces which act in those electric furnaces (like those in Fig. 9), and which gave rise to much of this discussion, is very difficult, as the current densities are very high and the heating is very great, enough to vaporize mercury very quickly and to melt solid conductors. Moreover the results are very apt to be masked by forces foreign to the one being studied. The position of the leads also is likely to affect the results and perhaps greatly; it is known that the pinch effect is very greatly affected by neighboring currents or magnetic bodies like the iron of which the electrodes were made. It is also possible that the Hall effect (variously defined) may become formidable enough to be involved. Alternating currents were used, and some of the results might be different for direct currents.

Concerning forces caused by magnetic flux, attention should also be called to the fact that the density or intensity, as distinguished from the amount of flux, may determine the resulting force on a conductor. In the case of a liquid couductor in a channel which turns a corner, the forces caused by the flux will be quite different on the inside of the corner where the flux is denser than on the outside where it is far less dense. Similarly, when a relatively small channel containing a liquid conductor discharges into a large bath of conducting metal, as in some furnaces, one must expect that any forces due to the flux, may change abruptly at that point. In the case of a current-carrying conductor leading vertically into the ocean, there would be very decided magnetic forces around the conductor, but none that are perceptible in or above the ocean; the magnetic effects then act as though they were dispersed.

In an air gap of a magnetic circuit the lower pole of which was large while the upper one was sharply pointed, the writer found that a fragment of iron resting on and held by the lower pole would be lifted up to the upper one, where the same field was denser.

It is hoped that the facts and suggestions given above which were brought to light by these high-current density phenomena, will encourage further research and discussion among those best able to study the subject. At these very high-current densities forces become formidable which under ordinary conditions were too small to be noticed.

PHILADELPHIA,
MARCH 14, 1921.

Pure Platinum.—According to EDWARD WICHERS, of the Bureau of Standards (*Jour. Am. Chem. Soc.*, 1921, xliii, 1268–1273), platinum of a high degree of purity may be obtained by repeated precipitation as ammonium chloroplatinate; four such precipitations are usually sufficient. Each precipitate is washed two or three times by suspension in a rather large volume of a solution of ammonium chloride containing from 15 to 20 per cent. of that salt. The washed precipitate is collected on a filter, dried, and ignited to platinum sponge in an electrically heated muffle furnace. The sponge is converted into hydrochloroplatinic acid by means of aqua regia; and the entire cycle of operations is repeated. The final ignition is made in a porcelain dish, in an atmosphere of hydrogen; the dish is covered with a silica plate, and heat is supplied by a gas flame.

The sponge was melted to a button on lime by means of the oxyhydrogen flame. Platinum with a minimum calcium content was obtained when a considerable excess of oxygen was present in the flame. Apparently, if the flame contains insufficient oxygen, lime is reduced to metallic calcium which passes into the platinum. When the fusion on lime was made in an electric induction furnace, contamination of the platinum by calcium did not occur to any appreciable extent. When platinum was fused in an induction furnace, which was lined with magnesia, with or without magnesium fluoride as a binder, the platinum was contaminated with as much as 3 per cent. of magnesium, possibly as a result of the dissociation of the magnesia at the temperature of the furnace.

By this technic platinum has been obtained with a calcium content probably not in excess of 0.0001 per cent.

J. S. H.

GEOLOGY IN PARTNERSHIP WITH AMERICAN INDUSTRY.*

BY

GEORGE OTIS SMITH, Ph.D., Sc.D., LL.D.

Director, U. S. Geological Survey, Department of the Interior, Washington, D. C.

TWENTY-FIVE years ago the college student was fairly certain in making his choice of a life-work between science and business. Then the dividing lines were fairly distinct between a life of quiet study in a search for truth and a life of strenuous activity in a struggle for wealth; now much of that distinction has been lost, for we find science and business working together and the scientist even earning a salary comparable with that once thought of only as the compensation of the merchant prince or the captain of industry. It is because of these changed conditions that I have followed the thought of Editor Rickard, of the *Mining and Scientific Press*, that the geologist "has developed from the academic student of Lyell's and Murchison's time to a pioneer of commerce; he has been required to submit his work to the test of economic usefulness, and he has succeeded triumphantly; he has become a real partner to the engineer and to the capitalist, and they appreciate his comradeship." With that thought in mind I will discuss with you the partnership of geology with industry.

Science of all kinds has become more practical; whether we who chose science as a shrine at which to worship like it or not, science has become a centre of service. This utilitarian trend of science has logically brought it into close touch with industry, and the scientist can now claim partnership with the industrial executive.

The linking of scientific research with industrial practice has in recent years found definite expression in the system of industrial fellowships. The latest administrative report of such an industrial experiment-station in your own State lists nearly fifty of these fellowships, and I was interested to note that nearly one-fourth of the subjects under investigation are connected with the utilization of mineral products. This is a very practical kind of partnership between science and industry, and the fact that industrial corpora-

* Presented at a meeting of the Mining and Metallurgical Section held Thursday, April 7, 1921.

tions and associations of manufacturers are investing increasing amounts in technical research under truly scientific auspices is proof enough that the partnership has profits to divide. Although it may seem to have been long delayed, recognition of the practical value of theory is now widespread.

In referring to this delay, however, I am not forgetful of the occasional flashes of such recognition far back in our history. Indeed, the very name of this Institute recalls that pioneer American in whom an interest in science and a knowledge of practical affairs were so happily blended, that unique citizen, Benjamin Franklin, who was at once a leader in scientific thought and economic writing, a competent business man at home, and a brilliant diplomat abroad. Citizenship of that type is never out of date.

Geology was never a closet science: its subject is this earth of ours, and its field is all-out-of-doors. The horizon of the geologist is wide, and his contacts with life are many, so that geology has most naturally come into touch with human needs and by that association has become more and more practical. Yet for a long time geology was preëminently an amateur study: any reviewer of the contributions to geologic science would give a large share of credit and honor to students who can not be considered professional geologists. In geology, as in other branches of science, the only compensation offered to many of the leaders was their recognition by other scholars, and sometimes not much of that. Even here in America in more recent times only a few positions have been available for geologists, either as teachers in the larger colleges or as investigators on state or federal surveys.

Only as the utilitarian value of geology has become recognized has a use been found for geologists. Forty-odd years ago, in a congressional debate, the practical functions of geology were specified as to "prevent the waste of natural resources, clear the way of progress, and promote the triumphs of civilization." Those specifications might be rewritten in plainer language to-day, but even in those well-rounded phrases the task of the geologist is happily stated. To discover and measure the resources of the earth and to show how they may be utilized is a very practical part to play in this world of work.

The professional geologist is very much a modern product; indeed, it has been given to us of this generation to see geology establish itself as a partner of business. It was in the last fifty

years or so, that geologic principles and methods were first applied in a professional way to the hunt for oil, and only in the last twenty years has oil geology become essential to the oil industry. Within a single decade the number of petroleum geologists in consulting practice increased from two or three to several score, and in addition geological staffs have been built up by the oil companies themselves. To-day the most thriving of geological societies the world over is the American Association of Petroleum Geologists, which has more than 600 members and maintains a high professional standard of membership. So large a growth of a single branch of a profession is hardly possible except as it springs from service rendered.

This rapid expansion of the field of oil geology, like the mushroom growth of the oil industry itself, has attracted wide attention, yet the principles of petroleum geology are thoroughly scientific, and the petroleum geologist is not the only type of geologist who is in demand for practical service.

Science and industry in their present-day progress are treading paths that converge, until they are now well within each other's sphere of influence. Science is becoming more useful, and industry is becoming more efficient, and this mutual approach means a mutual attraction. I may illustrate this by pointing to the gratifying tendency of up-to-date constructing engineers to consult geologists upon questions related to large engineering projects. To the trained geologist, familiar with the many kinds of rocks and their varied habits of assembling, it has seemed strange indeed that so many engineers have gone ahead with great works of construction on the theory that rock is rock and that nothing can be learned of the third dimension of the earth's crust in advance of actual excavation. Possibly, however, some of this blame for their neglect of the geologist may be laid at our own door, for all of us do not seem to be firm believers in the practical value of our own science, and only in these later years have we learned to talk of the facts of geology with any approach to the quantitative exactness that the engineer requires.

The standing of science in the world of affairs has been greatly changed in recent years. As Doctor Little says: "The war has at last placed science above the salt, even at bankers' dinners," and we can also claim for geology what he says of his own science: "Chemistry is saluted by the man on the street."

We may take as a sign of the times a recent editorial in a leading newspaper of the South, in which this changed attitude is mentioned, "condescension or indifference, if not hostility," giving place to recognition that to such patient seekers after facts as the chemist and the geologist are we "chiefly indebted for material progress and ever-widening opportunities." That editorial utterance is a gratifying tribute to the scientific worker "who explores matter that he may capture it and coerce it into human service."

That the geologist has won a high place in the world is gratifying, but that place carries a corresponding degree of responsibility, and we may profitably review the steps that have led up to it and see what are the requirements of service imposed on the present-day professional geologist.

The demand for industrial geologists or geologic engineers is not altogether of recent origin, for the search for raw materials is not new. The earlier geological surveys aimed in a somewhat indefinite way at the development of resources, but immediately after the Civil War geologic exploration took on more of a professional character and connected itself with railroad building. Then began the hunt for traffic business through mineral discovery and mine development. The scientific investigation of the economic resources of the New West was systematically undertaken, and some of the traditions of these pioneer surveys have continued to our day. The development of our material resources was then, as now, recognized as a problem demanding scientific research, and the philosophy of the industrial conquest of a continent was clearly set forth forty years ago by Clarence King in his plans for the future of the United States Geological Survey. Director King then stated that without full scientific knowledge of all the elements of national wealth—especially the mineral commodities and products—commerce is mere transportation, industry is short-lived, and the economic equilibrium of population with local resources is not to be attained. To promote the progress of industry was even then the self-appointed task of geology.

The two basic productive industries, agriculture and mining, have long been served by geology, and this close relationship was most keenly realized during the World War, when food and munition requirements demanded in turn new sources of fertilizers and other raw materials. Thrown as we were upon our own resources

as never before since Colonial days, we had to recognize the geologist as a partner in our industrial expansion who could not be spared, however strong might be his personal preference for overseas service. The raw-materials problem was one we had to solve to meet the exigency, and now that the exigency is happily past we find ourselves studying our material resources with a new and broader outlook. A specialized type of geology is now demanded—the application of geology in terms of commerce; and to be most useful geology must occupy conjointly with industry the whole field of commerce, which is the whole world.

The dominant position of the United States in its supply of most of the essential minerals is only the starting-point in commercial geology: the worker in applied science of this type must interpret his facts of ore occurrence in terms of use and of value to mankind. The geologist or mining engineer who examines a Nevada ore deposit must bring to his task an eye trained to see far beyond the Basin Ranges that form his actual horizon: his experience and his store of information must endow him with the power to take the international view of mineral resources and of the industry and commerce that are founded on them. At this desert prospect the geologist must not only see the ore minerals as they occur here, deposited and enriched by the processes of nature, but must compare the quality and quantity of the unmined ore here with the similar facts of nature that give value to the ores in other districts, whether in Peru or in distant Burma. It is not simply the geologic problem of metallic minerals outcropping on a Nevada mountain side, for the geologist's vision must include also the industrial and commercial problems of the smelted ore and refined metal on their way to the markets of the world. In terms of commercial geology ore deposits take on competitive relations, which depend in turn upon the geographic facts of distribution—not only the location of this or that body of ore, but its distance from the supplies of fuels, power, and labor required to win the metal from the ore, and finally the distribution of the markets where the metal can be put into the service of mankind.

Thus to broaden and extend the geological engineer's vision is not to commercialize his science, though it surely does make it more useful. The scientist may be obliged to translate some of his technical terms into the language of the market-place, but in this translation he will perceive that a larger duty has come to him—

the duty of interpreting the facts of his science in their relation to national life.

The United States Geological Survey has just issued the first volume of a World Atlas of Commercial Geology, a work planned for the desk of the business man as well as for that of the college student. This atlas exhibits graphically the distribution of mineral wealth over the entire surface of the earth, for one of the lessons we learned in the school of war was that it is not enough to know simply what America contains and possesses—we must know the mineral wealth of the world, exploited and unexploited, in all its continents and countries.

These facts, as disclosed in maps and text, sustain in part the patriotic pride we feel in our national primacy in mineral wealth; but they also no less plainly appeal to our patriotic regard for the future continuance of our present prosperity. To be adequate any stock-taking we now attempt must include world resources and world needs and by balancing production against consumption must set forth a true picture of world competition, for under the complex requirements of present-day life no continent, not even North America, can be self-sustaining. It is no longer enough for us to make an inventory of the mineral wealth of the United States: we must supplement that inventory by a broad understanding of world demand and supply.

The raw-material issue will last through the centuries; but unlike the foodstuffs, whether corn or cattle, or the fibres, whether cotton, wool, or pulp wood, the minerals, such as oil, coal, copper, or iron, have but one crop to harvest. The duty laid upon the geologist to discover every mineral deposit and to disclose its limits thus becomes more than a service rendered to his employer, the landowner or mine operator: it is a part of the national undertaking to determine the assets available for use by this and future generations.

The industrial resources of a nation are made up only in part of its supplies of raw material, for labor, power, technical ingenuity, managing skill, and capital are other constituents that enter into the composite reaction that we term industry; yet possibly that stage in world development has now been reached in which the present output of raw materials is fairly indicative of national rank in natural wealth. Undoubtedly this or that country is living far beyond its means in its annual output of this or that product of its

mines, and too soon its store of mineral treasure will be exhausted; on the other hand, some countries possess virgin resources that still await utilization. Thus the statistics of the mineral production of Europe and North America, which contain the workshops of the world, doubtless overemphasize the relative importance of these continents as future sources of mineral commodities compared with frontier continents like Africa and South America.

The practical value of this exhibit of the world's mineral assets is evident. Experience gained during the World War emphasizes the advantage of an adequate supply of raw materials close at hand, yet that there are certain economic limits to domestic independence in raw materials is clearly shown by the readjustments already made. The more facts we possess bearing upon the relative quantity and the relative availability of the mineral resources of our own and other countries the better able will be our captains of industry to decide whence they should derive their raw material. But the output of raw minerals measures only the first step in industry. The mines of the United States should be looked upon primarily as tributary to the many mills, shops, and factories in which the skilled labor of the country may find its opportunity for a livelihood. The production of crude oil, coal, pig iron, copper, or other raw minerals for export is surely less desirable than their production for home consumption. Then, too, both commerce and industry need not only exports but imports, and raw materials may well supply this need. Knowledge of what the whole world contains is plainly the best basis for discussing public policy and planning private business.

We need to realize that American industry has reached the intensive stage. Six years ago I had the privilege of discussing here in Philadelphia the distribution of industrial opportunities as affected by the distribution of raw materials. In December, 1914, we were just beginning to readjust some of our industries to the use of American substitutes for imported ores and other mineral products, but already there had been some gratifying returns on the scientific study, through many decades, of the distribution of mineral resources that had not before been needed. Bits of knowledge that had been merely interesting became highly valuable, or, as I then expressed it—"The dollar mark attached itself to these facts over night."

American business becomes more and more complex as by-

products and side lines are added to industry and commerce. These additions are sure signs of economic progress, but this expansion necessitates the employment of specialists. As Dr. J. T. Young pointed out fifteen years ago, when he was Director of the Wharton School of Finance and Commerce, this expansion of business broadens the field for the man of scientific training: the widening of the business horizon has created the need for men of broader vision. The larger the business undertaking the greater its need of a staff of technical advisers who can see markets and supplies in terms of a generation rather than of a fiscal year—men who can measure the unseen and weigh the undiscovered. In planning for the future we must reckon with possibilities and probabilities. So it is that many corporations other than mining companies now employ geologists. Raw-materials specialists are employed to hunt for the needed supplies, and I notice that one former associate of mine has been engaged by a glass company; another geologist has gone into the employ of a maker of lumber substitute, and still another is serving the needs of our largest by-product coke company.

I have mentioned the fact that geology has begun to meet the engineer's demand for exactness as well as the business man's demand for usefulness. You may ask how successfully the oil geologist, for instance, has met the test. It is true that hard-headed men of business, who formerly gave scant courtesy to science, now employ geologists, but with what result?

The first duty of the oil geologist is self-evident—to find the oil. To discover a resource that is so deeply hidden seems almost the trick of a magician, and the unscrupulous expert is willing enough to enshroud his acts in mystery. Yet oil geology is not magic, but simply common sense backed up with a large collection of carefully observed facts. The stimulating and strengthening element in the growth of oil geology has been the promptness of the test to which the geologist's judgments are subjected. The drill shows up the value of his science before he can shift responsibility. To convince a former chief of mine that the oil geologist is right more than half the time, I had a test made of the measure of agreement between the structure mapping and the results of the drill. The study covered a number of townships of the Osage lands, a region which perhaps favors the geologist more than some others, but care was taken to include townships in which the

geologic relations were not wholly plain as well as those where the structure had been worked out to the satisfaction of the geologist. A few productive wells were found near synclinal axes and some dry holes were found on anticlines, yet this impartial study showed that the geologist, when his work was tested by the drill, had been right 87 per cent. of the time. The public can ask of science no better percentage of successful achievement than that, and if the business of the country were conducted with the same degree of accuracy the high cost of living would be a less troublesome economic issue.

In its partnership with industry, geology can bring into service a special talent. The science of geology deals with earth elements not only in the mass but also in their setting in time. The geologist is truly fortunate in possessing this sense of time. With his eye trained to see far back into the earth's remote past, he is better fitted to put correct values upon the episodes of the brief present day in which we happen to live. Intellectually this long backward view gives him poise; practically this ability to see things in true perspective leads him to plan intelligently centuries ahead. This picture of the geologist as one who is gazing into the future with large practical foresight runs counter to the popular conception of him as one who is ever poring over the dusty records of the past, yet I believe the working geologist of to-day is really inspired with this purpose to do his part in insuring the continued welfare of his country. Prosperity will fail to satisfy us unless it is backed up with guaranties of permanence. Whatever we are to enjoy this year and next year we wish our children's children to enjoy in equal if not in larger measure. We ought to take out nation-wide insurance to cover this forward-looking wish, if we can.

So I believe it is especially true of the geologist that his training has made him look forward—he is concerned for the future of his country. As an engineer he examines the foundations of national greatness to see if they promise to stand the test of time, and his desire is to make them serve many days and generations. Thus the geologist thinks of American industry as founded on stores of energy and of raw material, and he studies the geography of industry—its sites and its markets—in terms of adequacy and permanence of resources. After our war experiences it was natural that the geologist should discuss the economic limits to domestic independence in minerals. There must be some economic limit to

this possible self-sufficiency, even in a country so wealthy in raw materials as our own. With the question of adequate supply, which was uppermost during the war, is now joined the question of satisfactory price, which regains its old-time prominence with the return of competitive conditions. Yet the pendulum of economic thought can not swing back to its former extreme: the truths learned during the war exercise a drag that ought to keep our thinking somewhat nearer the normal.

The first lesson we learned in the experience of meeting the insistent demands of a war program with its rapidly expanding industries was to think in terms of quantity of a commodity rather than of its cost. So while we can no longer afford to pay any price for immediate delivery we realize better that quantity is the truer measure of usefulness and that the totals stated in dollars may not express the advances in industrial growth they seem to show. We have lost some of our old-time faith in the dollar as a standard measure of value.

Connected with this emphasis upon tons rather than dollars in considering the mineral raw materials is the necessity of thinking in terms of low costs rather than in terms of high prices. The day of excess profits that came through over-high prices ought soon to pass, and the day of lower levels of both cost and price ought soon to dawn. The producer of raw materials, whether farmer or miner, surely deserves his share, but in discussing profits to owner or wages to worker the truth should never be overlooked that the market price of the mineral fuel or of the ore is but the starting-point of some other industry, and only disaster can result from keeping a price too high. The rôle of the mineral industry is not to exploit markets but to supply consumers.

Industrial expansion on the scale imposed upon our country as its part in the war also cleared our judgment as to value in terms of utility. Gold was not one of the "war minerals," the increased output of which engaged the best efforts of geologist, metallurgist, and mine worker. Gold may have had its place in the war chests of militaristic nations, and it continues to hold its place as the universal measure of value, but gold is not a raw material whose general utility is at all comparable with that of its more democratic fellows like iron or copper. Indeed, there is some reason to liken this "noble metal," which has so long held the allegiance of mankind, to the idle aristocracy of Europe and to

suggest that the more abundant the world's supply of gold the poorer off we are in the humble but useful things of life. It is a nation's output of coal and iron, petroleum and copper, sulphur and lead, cement and zinc, brick and aluminum, that gives it power, rather than its output of gold and diamonds. The war-time effort to rescue platinum from its associations with luxury and idleness and draft it into the service of war industries was a tardy public recognition of the fact that this precious metal is also highly useful.

I have already referred to the dominance of the United States in so many of the essential minerals. A simple comparison of the statistics of production and consumption in different countries is enough to prove that America is in the highest degree self-sufficient. In the five essential mineral raw materials coal, iron, copper, lead, and zinc, for example, the United States in 1913 showed an aggregate exportable surplus of 24 per cent., whereas Germany's deficiencies in these same essential minerals amounted to 40 per cent. Such facts at least suggest that America can be progressive and generous for the same reason that Germany was tricky and relentless.

The geologist's best contribution to industry is perhaps his advice regarding the future; he believes in the future prosperity of his partner, but feels the need of planning for it. Resources are expendable, but industry is long-lived. The geologist believes that he sees plain facts spread over the face of this old earth as well as through the pages of history, and he is keen to safeguard the future security of the American industrial program. The bounty of Nature has bred into our American life that type of optimism that thinks too little of the morrow. To offset this blind faith in future security, the geologist has had to be the first to utter the note of warning that the oil supply is not unlimited—and indeed our vast stores of coal are not so distributed that thrift in the use of coal is an unnecessary national virtue. The geologist accepts his responsibility for increasing the accuracy of the inventory of the country's natural assets and for bringing home to the people a full realization of the future value of these expendable resources. It is in view of these opportunities of the geologist to help make safe the future of the country that I have come to think of geology as a phase of citizenship rather than as merely a branch of science.

In any articles of copartnership that may be drawn up between geology and industry there should be full recognition of the radical difference between the character of the work of the partners; the stop-watch can not be held on science, nor can the line of research be rigidly plotted—short cuts in science are not to be relied upon.

Partnership understandings between science and industry should provide for credit for by-products. Research may fail to deliver the results sought and yet may uncover a side line of even greater value. The advantage of the scientific method of collecting facts and deducing principles is that the facts and principles thus acquired have their own value; and this may mean their usefulness for some other purpose even if the immediate result is negative. The geologist who returns with an adverse report on an oil lease may have worked out criteria by which he later, and in another county, discovers a new oil pool.

The geologist on his side owes it to his prosaic partner, who thinks in terms of results, to see that no esoteric glamour is thrown over his methods of investigation. True science is not magic, and there is so much of common sense in what we term geology that whatever we really know can usually be explained in plain English. Ultratechnical language may camouflage hazy thoughts; and though scientific terms have a proper function in labeling our properly arranged collections of exact facts, such terms neither describe nor explain the truths of nature. The practical man of business is warranted in not giving too much credit to the geologist who can not tell his story in common language, and the world should be especially suspicious of those of us who persist in concealing our thoughts or lack of thoughts under a protective cover of professional jargon. The most valued commendation I ever received was given to me by a well-known captain of industry in his comment that I had told him things he ought to know in words that he could understand.

Another phase in this partnership between science and industry partakes more of the personal relationship, and that is the taking over into the business world of scientific ideals and scientific standards. Here is something that may be termed a professional obligation of the geologist—the recognition of our science in the market place counts for little unless we see the opportunity for our science to coöperate in the raising higher of our business ideals. A

geologist can have no double standard—one to guide his research work in pure science, the other to measure off his answer to a practical question. The same exact method, the same fair judgment, and the same fearless decision must mark his activity in the world of work as in the world of study.

There is not even yet the widespread respect for specialized science that would seem to be warranted by the type of its service. A better understanding of the task of the specialist, of his training and his methods of investigation, is needed to give effectiveness to his work on some practical problem. The popular idea that a professor could be put at almost any job received the stamp of governmental approval during the war, when splendidly equipped specialists were ordered to show their genius in learning the tricks of another trade, and when work in their own lines was assigned to specialists in others. In terms of shop management and industrial efficiency the Washington method was most wasteful, yet I fear that it only reflected the popular ignorance regarding specialized science.

Geology is distinctly a specialized science, and as such it can render its own special service to industry. I have outlined the part played by geology in our national development, and I have suggested, I trust, the larger share that this branch of science can have in helping industry win for us a greater national prosperity. But the popular appreciation of the scientific aid rendered in the utilization of these resources is still far from adequate. This is the human side of so material a subject as mineral resources. I know the scientific worker's intense devotion to the public service, and I crave for him the larger recognition that is his due. The geologist can help in the world's work and he wants to help more.

Atomic Weight of Zinc.—GREGORY PAUL BAXTER and JAMES HALLETT HODGES, of Harvard University (*Jour. Am. Chem. Soc.*, 1921, xliii, 1242–1251), prepared pure anhydrous zinc chloride by the action of a current of dry chlorine gas upon anhydrous zinc bromide. They then analyzed this zinc chloride in aqueous solution by means of the electric current, using a mercury cathode for deposition of the zinc. Their results showed 47.970 per cent. of zinc to be present in the zinc chloride; hence the atomic weight of zinc is 65.38.

J. S. H.

Cistern Filters not Germ-proof. (*U. S. Geological Survey Press Bulletin No. 478*, October, 1921.)—Cistern water that is used for drinking should be gathered with great care. Properly constructed cisterns that receive rain water from roofs generally afford good drinking water, but water of doubtful quality that is stored in cisterns is of course not safe for domestic use. According to the Survey most of the filters that are used in connection with cisterns do not remove the germs of disease, though they may make the water clear and apparently safe. Many cisterns are divided into two compartments by a brick wall, the water being admitted into one compartment and pumped or drawn from the other after it has passed through the wall. The passage of the water through the brick improves it in clearness and color, but not generally in sanitary quality.

A Study of Frary Metal—Calcium-Barium-Lead Alloy.—The importance of this alloy lies in the fact that the shortage of antimony at the beginning of the war led to investigations for substitutes, especially in the manufacture of shrapnel bullets. Frary and Temple procured patents for alloys of barium and calcium with lead. Owing to the increased use of gas shells, the demand for shrapnel fell off, but the alloy was found to have practical value as a bearing metal. The Bureau of Standards reported favorably on it, having obtained better results than with standard babbitt. The alloy is now made on the large scale. Cowan, Simpkins and Hiers, of the research laboratory of the National Lead Company, have made studies of the alloy as produced electrolytically, and give the results of this study in a paper presented at the fortieth meeting of the American Electrochemical Society. The procedure of manufacture consists essentially of placing mixed calcium and barium chlorides upon a mass of high-grade pig lead in the molten state. Each pot is provided with an adjustable graphite anode. The anode is first immersed in the chloride mixture and the current turned on. The resistance is sufficient to melt the mass, when the calcium and barium set free are absorbed by the melted lead. (Compare, in this connection, the note concerning lead-sodium alloys, in this journal for October, 1921, p. 452.) The operation is conducted until the proper amounts of calcium and barium are introduced into the lead the fact being ascertained by occasional testing of samples. The alloy thus produced is essentially a ternary alloy, containing up to 2 per cent. barium and 1 per cent. of calcium. Small amounts of mercury may be added. Equilibrium diagrams and metallographic views are given.

H. L.

A PHOTOMICROGRAPHIC METHOD FOR THE DETERMINATION OF PARTICLE SIZE OF PAINT AND RUBBER PIGMENTS.* †

BY

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WHEN a biologist desires to measure the diameter of a tissue cell or the length of a bacterium he may use for his purpose a filar micrometer eyepiece calibrated by means of a stage micrometer. Aside from a certain amount of facility required for the manipulation of this instrument his task is a comparatively easy one. Objects like cells, etc., possess, as a rule, a high degree of uniformity with the consequence that a fairly accurate average diameter may be obtained with relatively few measurements. Further than this it is not a vital issue with the biologist if his average measurement, so obtained, happens to deviate from the most probable value by the apparently insignificant amount of one- or two-tenths microns.

On the other hand, the microscopist who wishes to determine the average particle size of a paint or rubber pigment has a problem to deal with which, in a sense, is diametrically opposite to the case just cited. Here, even in the most uniform pigments, will be found particles ranging from the nearly or quite ultramicroscopic to those with a diameter many times as great. Hence, it sometimes becomes necessary to measure thousands of particles, if a high degree of accuracy is required, in order to obtain a value that closely approximates the true average. To try to accomplish this with a filar micrometer would not only consume an unwarranted amount of time but the process itself would become so tedious that it would discourage, at the start, anyone who attempted to solve the problem in this manner.

Then again, the matter of accuracy assumes here a truly important rôle. A few years ago the technical advisor who would

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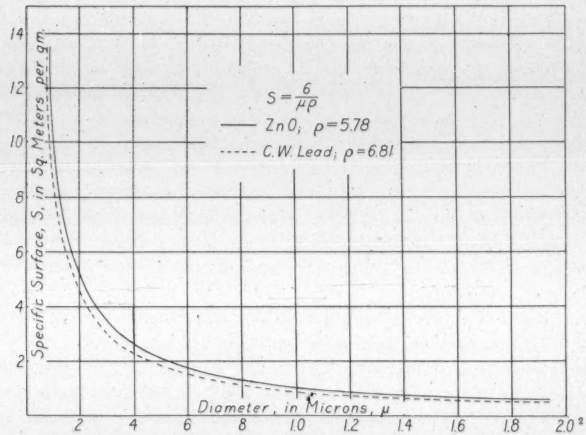
* Communicated by the Author.

† The expression "Particle Size" is used in reference to diameters, as customary amongst paint and rubber technologists.

condemn a consignment of pigment on a matter of one-or two-tenths microns (if he were able to detect it) would have been considered hypercritical to say the least. But let us see if such a hasty conclusion arrived at without due consideration, is justifiable or not.

The character and behavior of fine pigments depends to a large extent on the magnitude of their specific surface.[1] Assuming the particles to be spheres, simply for the sake of simplicity—

FIG. 1.



Curves for zinc oxide and corroded white lead, showing relationship between specific surface and diameter of particle.

and this assumption cannot fundamentally alter the argument—it can be shown that,

$$\rho S \mu = 6 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (I)$$

where, ρ = density of material.
S = specific surface (square metres per gram of material).
μ = diameter of particle in microns.

[1] Specific surface is inversely proportional to the "diameter" of the particle or to "particle size." Such qualities of a pigment as tint, brightness, hiding power, and oil absorption, in paints, and resistance offered to abrasion in rubber are functions of particle size. It would be a great mistake, however, to assume that these qualities depended *entirely* on particle size. Other factors enter in, such an index of refraction, density, color, forces of adhesion and surface tension.

[2] If μ is the harmonic mean of the three dimensions, then this equation will hold for any rectangular parallelopiped. Pigment particles roughly approximate this form and that of spheres.

Plotting the equation for zinc oxide ($\rho = 5.78$) and lead carbonate ($\rho = 6.81$) gives the two curves illustrated in Fig. 1. It should be noted that when the pigments are comparatively coarse, from .8μ in diameter upward, a difference of .1μ or .2μ has but little effect on the magnitude of the specific surface. From .8μ downward, however, the reverse of this condition becomes true. In the case of very fine pigments such as zinc oxide it will be found possible to purchase on the market various grades of material some of which will measure .6μ and others only .3μ—a total range of but .3μ, yet one sufficiently great to cause a difference of 100 per cent. in the specific surface. Studying the situation from this point of view will show that the investigator who considers the importance of one- or two-tenths microns is not so fastidious after all.

As a matter of fact the author feels no hesitancy in predicting that within the next few years the manufacturer of fine pigments who wishes to maintain his position in a keenly competitive field will find it necessary not only to become acquainted with the particle size of his products to the first, but even to the second, and probably the third, decimal place in microns.

THE METHOD.

The fundamental idea involved in the method is by no means a new one. In all probability it has been employed many times by various investigators and for numerous purposes; yet the author is not aware of a single case where it has been sufficiently developed in detail so as to make it of practical importance in the special line of work to which it is here applied.[3]

Briefly stated, the pigment is prepared in such a manner so that a photomicrograph, at a known magnification, can be taken, showing *clearly and distinctly the individual particles,* which are then measured from the negative by a method to be described presently.

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[3] The method of grain measurement exployed by metallographers is fundamentally similar to the photomicrographic method of particle measurement. Note on grain size, by G. H. Gulliver, *J. Inst. of Met.*, 1918.

"The Determination of Grain Size in Metals," by Zay Jefferies, A. H. Kline, and E. B. Zimmer, *Trans. Am. Inst. Mining Engineers*, 1917.

PREPARATION OF THE SAMPLE FOR PHOTOGRAPHING.

About a milligram of the pigment is placed on the centre of a microscope slide to which is added a drop of redistilled turpentine. The slide is to be held at the two ends between the thumb and first finger; a glass rod, with smooth, straight sides, so that it will come in close contact with the glass, is now used to disperse and rub out into an extremely thin layer the material in the turpentine. This is best accomplished by a forward and backward motion of the rod in the direction of the length of the slide and extending over the central area only. The rubbing must cease at a certain critical stage, when there still remains sufficient turpentine unevaporated to prevent the mount becoming "streaky," and yet not enough to float the particles which would allow them to flocculate. By a slightly upward flourish of the rod on the last stroke the mount can be made wedge shape, that is, dense in one part and thin in another, with all intermediate grades of density between. In this way it becomes possible to select a section for photographing that will show neither too many particles nor too few per given unit area.[4]

The next step, after the material is properly dispersed, is to completely remove the remaining turpentine. This should be done by laying the slide on a hot plate, the temperature of which is sufficiently high to cause evaporation within forty or fifty seconds Care must be taken that volatilization is complete. This is satisfactorily ascertained by noticing if any odor of turpentine remains after heating. The particles will now be found to be cemented to the glass and should remain in this condition, if a reasonable amount of care is exercised in handling the slide. When suffi-

[4] This method of dispersing the particles is to be used principally with the finest pigments, such as zinc oxide, lithopone, white lead, etc. In the case of these materials it will be found impossible to produce any *grinding* effect that will cause the *individual* grains to be broken up into smaller ones. This is on account of the fact that neither the glass slide nor the rod are optically flat, and consequently they are unable to come in close contact with each other except at a very few points.

With coarser materials such as clays, barytes, asbestine, etc. (which will probably feel gritty), only the slightest possible pressure must be brought to bear upon them with the dispersing rod for here there is some danger of a real grinding effect becoming manifest. Fortunately, these materials are so large that flocculation does not prevent the outline of the particles from being seen and a measurement made, hence, very little rubbing is necessary.

ciently cooled a small drop of glycerine is placed on the centre of the mount and then covered with a thin slip. The excess glycerine must be carefully squeezed out at the sides of the cover glass and absorbed by filter paper. The mount is finished in the usual manner with a ring of Brunswick black.

If the above instructions have been properly carried out, and the mount now held to the light, the pigment, if its index of refraction is high, will just be perceptible as a faint cloud; if its refractive index is low, the pigment will be entirely invisible, except with a microscope.

Upon microscopic observation three essential conditions should be manifest. They are—

1. The particles will be in one plane.
2. They will be free from Brownian motion.
3. They will be dispersed, showing individual grains instead of aggregates and flocculates. (Compare Figs. 8, 9, 10 and 12 with Fig. 7.)

THE PHOTOGRAPHY.

It is not the purpose of the present paper to describe the method of using a photomicrographic apparatus. It is also hardly necessary to add that unless one has acquired considerable facility in the manipulation of such apparatus it would not pay to attempt its application in the measurement of particle size.

In regard to the present problem, however, it must be stated that all photographs are made with transmitted light, and that this light is to be absolutely axial. Obliquity of illumination will give a distorted image, causing an appreciable error in the results.

The beginner will find it advantageous to start with a fine-grained contrast plate, using hydroquinone developer. After he has obtained experience in handling these materials successfully, he should then try his ability with panchromatic plates and develop with pyro. There are plates of this kind made especially for photomicroscopy which give great detail together with sufficient contrast.

THE MAGNIFICATION.

Generally, in photomicrographic work, definition of structure is the one essential quality most desired. However, as the structure of a pigment particle will give us no information in regard to its size, the factor, definition, may be neglected here to a

certain limited extent.[5] On account of this fact it has been found an advantage to employ a magnification which otherwise would be too high if the best definition is to be obtained. Nevertheless, care must be taken that the photographic image of the particle gives edges sharply enough defined so as to make a satisfactory measurement possible.

With a 2 mm. apochromatic objective a magnification of 1500 diameters will be most convenient for pigments such as zinc oxide, lithopone, red oxide of iron, sublimed white lead, corroded white lead, Mathewson white lead, etc. Lower magnifications are used, naturally, with coarser materials. The method of measuring magnification is given under the section entitled "Errors."

MEASUREMENTS.

As previously pointed out, it sometimes becomes necessary to measure a thousand or more particles in order to obtain a sufficiently accurate average diameter. This demands a rapid method of measurement, if the work is not to become too irksome. The method is as follows: The negative, which must show from 200 to 250 distinct particles, is placed in a stereopticon and an image of it thrown on a screen, so situated that the total magnification of the original particle will be from 20,000 to 25,000 diameters. The image of the particles is measured with a millimetre rule. Particles which are out of focus to any extent at all, as the case will be with those around the border of the negative, must be neglected. In order to eliminate the possibility of duplication and skipping, the area of the screen is divided into small squares.

It is neither necessary nor desirable to consume time in estimating the fractional part of millimetres. These small errors are just as liable to be positive as negative, and it is reasonable to believe that their sum approaches zero as the number of measurements increases.

The length of time required for the measurement of a single particle should be approximately two seconds. As the readings are called off an assistant may take them down on an adding machine regulated to record number of items, so that by the time the measurements are finished their average can be determined directly.

[5] But to no greater extent than is shown in the photomicrographs, Figs. 8 to 13.

If the probable error and the uniformity coefficient are desired, a permanent record of each particle is made by the method

FIG. 2.

Particle Measurement Record Sheet

Millimeters. m.m.	12-17-20 Zinc Oxide #3B 1st	Frequency. f.	fxmm	v	v^2	$f \times v^2$ (Σv^2)
1						
2						
3						
4						
5						
6	𝍸 III	8	48	4.44	19.71	157.68
7	𝍸 I	6	42	3.44	11.83	70.98
8	𝍸 𝍸 𝍸 IIII	19	152	2.44	5.95	113.05
9	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 III	53	477	1.44	2.07	109.71
10	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 II	82	820	.44	.19	15.58
11	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 I	46	506	.56	.31	14.26
12	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 IIII	34	408	1.56	2.43	82.62
13	𝍸 𝍸 II	12	156	2.56	6.55	78.60
14	𝍸	5	70	3.56	12.67	63.35
15	II	2	30	4.56	20.79	41.58
16	II	2	32	5.56	30.91	30.90
17	I	1	17	6.56	43.03	43.03
18	I	1	18	7.56	57.15	57.15
19	I	1	19	8.56	73.27	73.27
20	I	1	20	9.56	91.39	91.39
21	I	1	21	10.56	112.40	112.40
22	I	1	22	11.56	134.60	134.60
23	I	1	23	12.56	158.80	158.80
		276	2881			1449

Magnification, 20,000 diameters.

Average particle size $= \frac{2881}{276} \div 20{,}000 = 0.522\ \mu$

$P_{A_D} = \pm .6745 \sqrt{\frac{1449}{276 \times 275}} = \pm .093$

$P_A = \pm .005\mu$

Total probable error by Eq. XI, 1.37 %

Coefficient of Uniformity, $U = \sqrt{\frac{276}{2 \times 1449}} = .309$

employed in Fig. 2. The illustration is self-explanatory. Each stroke corresponds to a particle. The first column gives its measurement in millimetres at 20,000 diameters.

THE AVERAGE DIAMETER.

It is not always an easy question to decide which direction through the particle is its most representative "diameter." In measuring particles which approximate spheres in form, the best rule is to take only the horizontal direction. As the pigment grains will be orientated in every possible way on the screen, an average thus obtained will be, from a large number of measurements, not only the diameter of the average particle, but also the "average diameter" of this most representative particle.[6]

In the case of pigments composed of needle-shaped crystals, it is necessary to calculate the harmonic mean of the three dimensions of each particle. The negative, of course, is able to show only the length and width, and therefore the third dimension must be estimated. Fortunately most acicular crystals encountered in practice are either tetragonal or hexagonal and so the third dimension will be equal to the smaller of the two measurable ones. The average diameter will be the average of the harmonic means.

ERRORS.

The result of a series of measurements, giving an average particle size, will be of little value unless it is known just how much reliability may be placed upon it. In order to ascertain this, it is necessary to make a complete study of the various errors encountered throughout the process. These errors are given in Table I; and below are subjoined comments upon those requiring explanation.[7]

---

[6] If the average particle volume is desired to be known it is necessary to base calculation on some assumption as to the shape of the particles. It is usually customary to assume that they are spherical in form. It should be noted, however, that by this method of particle measurement it is not necessary to fall into the error of using the *cubed average diameter* in place of the *average of the cubed diameters*. In order to avoid this mistake it is only necessary to replace the column f x mm. in Fig. 2, by f x mm^3. If the work is made systematic and a table of cubes is employed no insurmountable difficulties should be encountered in doing this.

[7] It is not to be inferred from the above statement that Table I includes *every* existing source of error. Manifestly it would be impossible to create such a table. It is believed, however, that this section omits no source of error which it is reasonably possible to study. Consequently it must be emphasized that where the expression *total error* is used, it is "total" only insofar as it includes the errors listed above.

TABLE I.

Errors and Mistakes Encountered in the Photomicrographic Method for Determining Particle Size.

(I) Errors in Magnification.	1. Calibration of stage micrometer. 2. Measurement of image of micrometer on glass focusing screen. 3. Measurement of bellow's length. 4. Determination of the stereopticon magnification (a. The ruled lines; b. image on screen). 5. Distortion of image on focusing screen.
(II) Errors in Obtaining Average Diameter of Particle Aside from Errors in Magnification.	1. Errors due to the fact that the number of measurements cannot be infinitely great. 2. Errors from disregarding fractional parts of millimeters* in measuring image of particle. 3. Errors arising from the fact that the largest particles do not always occur with the proper frequency on a single negative showing but 200–300 particles. 4. Errors from poor judgment in selecting representative section for photographing. 5. Errors from diffraction effects, when particles, the diameters of which are less that the resolving power of the objective are photographed. 6. Errors due to distortion of the photographic emulsion, upon drying.
(III) Negligible Errors.	1. Errors in the ruling of the millimeter scale for determining bellow's length. 2. Errors in the ruling of the scale used in measuring the image of the stage micrometer. 3. Errors in the comparator.
(IV) Mistakes.	1. Poor focusing. 2. Oblique illumination. 3. Insufficient and excessive illuminations. 4. Underdevelopment and overdevelopment of negatives.

(I) 1, 2, 3. The magnification of the microscope is determined in the usual manner with a calibrated stage micrometer.

Instead, however, of using but a single determination, a number of such are made at various bellow's lengths.

Taking as the bellow's length, B. L., the distance between the smallest circle of light projected by the microscope,[8] and the ground glass surface on which the image is ultimately focused, a linear relationship will exist between B. L. and the magnification of the microscope, D_m, so that,

$$\frac{D_m}{B.\,L.} = K \quad \text{(constant)}$$

If, then, K should be known for any particular set of lenses, the magnification is easily determined from B. L. In calibrating the stage micrometer used in this work there was a probable error of 5.0 per cent. in the 0.01 mm., and 0.5 per cent. in the 0.10 mm. division. Obviously the larger divisions were the more desirable ones to use. Note carefully, however, the remarks given under "Distortion" in regard to the use of these large divisions.

Writing for D, $\frac{I}{.1000}$, where I is the length of the image on the focusing screen of the .1000 mm. division, we have

$$K = \frac{I}{B.L. \times .1000} \qquad \text{(II)}$$

If P is the probable error, then,

$$\left(\frac{P_K}{K}\right)^2 = \left(\frac{P_I}{I}\right)^2 + \left(\frac{P_{B.L.}}{B.\,L.}\right)^2 + \left(\frac{.0005}{.1000}\right)^2 \qquad \text{(III)}$$

Assuming, for the moment, that an actual error exists in the calibration of the micrometer, then its effect will be to produce a constant error in K, and consequently can in no way influence the "smoothness" of the D.–B. L. curve.

Therefore, only the slight inaccuracies in the measurements of I and B. L. will cause points to deviate from this curve.

By repeated experiment it was found that with no more elaborate apparatus than a thin-edged rule and a small hand lens, I could be determined to within 0.1 mm.; also, with suitable precaution the bellow's length could be measured to about ±1.0 mm.

In view of these facts it is obvious that that part of the error in the magnification due to the inaccuracies in the measurements of I and B. L. must be quite small; hence, the probable error will

[8] The eye-point.

not be appreciably affected if each point on the D.–B. L. curve is given equal weight.

Granting this, then for n points on the curve, equation (III) may be written,

$$\left(\frac{P_K}{K}\right)^2 = \frac{1}{n}\left(\frac{P_I}{I}\right)^2 + \frac{1}{n}\left(\frac{P_{B.L.}}{B.L.}\right)^2 + \left(\frac{.0005}{.1000}\right)^2 \quad \text{.....(IV)}$$

Should n be as great as 10, then the first two terms on the right-hand side of the equation may be considered negligible for practical purposes, and the error in K becomes equal to the error in the calibration of the micrometer.

With a 2 mm. Zeiss apochromatic objective and a 6X compensating ocular, K was found to be $25.96 \pm .13$.

(I) 4. An easy method for determining the stereopticon magnification, and one used by the author, is to cut two fine parallel lines in the gelatin on a photographic plate, previously exposed to light and developed to a good density. Next measure the perpendicular distance between these lines with a comparator. By means of the stereopticon an image of the lines is now thrown on the screen and measured and the magnification, D_s, determined directly.

If R represents the distance between these rulings and the subscripts I and N refer, respectively, to image and negative, then,

$$D_S = \frac{R_I}{R_N} \quad \text{.....(V)}$$

and,

$$\left(\frac{P_{D_S}}{D_S}\right)^2 = \left(\frac{P_{R_I}}{R_I}\right)^2 + \left(\frac{P_{R_N}}{R_N}\right)^2 \quad \text{.....(VI)}$$

The distance, R_N, need be determined but once, by taking the average of a number of comparator readings. The distance, R_I, however, varies with every readjustment of the stereopticon screen and on this account it is probably more convenient to take but a reading or two and allow for a probable error of 0.5 mm. Actual experiment will indicate that this value is about correct.

If D is the total magnification on the stereopticon screen (20,000 to 25,000 diameters for the finest pigments), then,

$$D = D_m \times D_S \quad \text{.....(VII)}$$

But $D_m = K \times B.L.$

Then the total error in magnification is,

$$\left(\frac{P_D}{D}\right)^2 = \left(\frac{P_K}{K}\right)^2 + \left(\frac{P_{B.L.}}{B.L.}\right)^2 + \left(\frac{P_{D_S}}{DS}\right)^2 \quad \text{.....(VIII)}$$

The B. L. which enters the third term in equation VIII is usually obtained from but a single measurement and has a probable error of about ± 1.0 mm. Note that this is not the same measurement of B. L. which enters into the determination of K.

In the results of the work presented in this paper the value of P_D was found to be ± 0.78 per cent. at 20,000 diameters.

For the calculation of the total error of average particle size, see Section (II), 1.

(I) 5. The direct method of determining magnification described under Section (I), is applicable only when apochromatic lenses are employed.

With a 2 mm. achromatic objective, distortion in the outer zones is so great that an accurate direct determination of magnification becomes impossible. When it is desired to work with such lenses, the following plan must be adopted: Produce a D – B. L. curve, using a low-power objective (16 mm.), together with the ocular that is to be used later on in conjunction with the 2 mm. objective. With this combination of lenses the rulings of the 0.10 mm. division will no longer fall in the outer zones of the field, and will, therefore, be practically free from distortion. Next determine the relative magnifying power of the 2 mm. with that of the 16 mm. objective. This is easily accomplished with a filar micrometer eye-piece, using some suitably mounted object, such as a fragment of a diatom, with sharp edges sufficiently close together.

The relative magnification of the high-power objective, multiplied by the value of K derived for the 16 mm. lens, will give the desired value for K.[9]

(II) 1. It is obvious that the greater the number of measurements from which the average diameter is derived, the nearer will this average be to the true value. As the number of measurements must of necessity be finite, there will always be a probable error due to this fact. This error is calculated from the equation,

$$P_{A_D} = \pm .6745 \sqrt{\frac{\Sigma v^2}{n(n-1)}} \qquad \text{.....(IX)}$$

where P_{A_D} is the probable error of the average at magnification,

[9] Even in the case of apochromatic objectives where distortion appears to be negligible, it is advisable to employ this method of determining magnification as a check on the direct method.

D; v is the amount the particle differs in diameter from the average, and n is the number of particles measured.

The actual size of the average particle is,

$$A_1 = \frac{A_D}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (X)$$

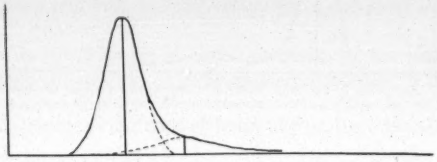
from which the total probable error, derived from the entire process of particle measurement, is obtained, thus:

$$\left(\frac{P_{A_1}}{A_1}\right)^2 = \left(\frac{P_{A_D}}{A_D}\right)^2 + \left(\frac{P_D}{D}\right)^2 \quad \ldots\ldots\ldots\ldots (XI)$$

The value of P_D is given by equation VIII.

(II) 3. If we have a pigment following a smooth curve law

FIG. 3.



The type of frequency distribution apparently caused by a mixture of two grades of the same pigment.

of distribution, and if it is found that in this material a particle of certain size should occur but once in a thousand times, then it ought not to appear at all on a negative containing but 200–250 particles. In actual practice such irregularities do happen and affect the average unfavorably. Therefore, in order to secure the most consistent results possible, a criterion of rejection is necessary.

There would be no difficulty in devising a suitable criterion if the curve followed the law of probability to its extremities. Unfortunately it does not always do this, and in such cases is apparently compound and derived from a mixture of different grades of the same pigment. (See Fig. 3.)

The use of any criterion of rejection, based on the mathematics of the probabilty curve, would therefore eliminate *entirely* the lower right-hand branch of such a curve with the result that the average obtained would be far below its most probable value.

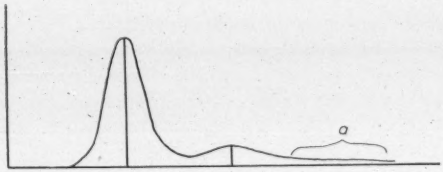
As the equation of a frequency distribution like that shown in Fig. 3 cannot be ascertained, the criterion of rejection, or more

accurately speaking a *method* of rejection, will necessarily be a somewhat arbitrary one.

METHOD OF REJECTION.

The method is to effect the extremity of the curve only. It is applicable when the pigment gives evidence of a smooth, continuous frequency distribution. When it is obvious that the material is composed of two or more grades of the same substance with widely different averages, as shown in Fig. 4, the rejection may

FIG. 4.



A frequency curve showing a mixture of ingredients with widely different average particle size. The method of rejection is applied to the portion of curve marked *a*.

be applied only to the right-hand branch of the curve furtherest from the origin.

Take the following example of the extremity of any suitable curve:

Frequency:	12	10	8	5	2	0	2	0	1	8	1	3
Millimeters:	15	16	17	18	19	20	21	22	23	24	25	26

It will be noted that from mm. 19 to mm. 26 the curve is practically straight and approximately parallel to the millimetre axis. This section may, therefore, be "smoothed" without introducing appreciable error. Bearing in mind that in measuring the images of large particles, such as mm. 21 for instance, there is liable to be an error of ± 1 mm., then it is reasonable to believe that one of the 21's is perhaps either a 20 or a 22. A 21 should be cancelled and either a 20 or 22 inserted; it does not matter which one is selected.

Upon further examination it appears that there are probably seven 24's too many and two 26's. Eliminating these and rewriting, we have:

Frequency:	12	10	8	5	2	1	1	0	1	1	1	1
Millimeters:	15	16	17	18	19	20	21	22	23	24	25	26

There is still the vacancy at 22 to be accounted for. As 23, 24 and 25 each occur, it is more probable that there should be a 22 rather than a 26. Again rewriting, gives us the final form of the curve:

Frequency:	12	10	8	5	2	1	1	1	1	1	1	
Millimeters:	15	16	17	18	19	20	21	22	23	24	25	

This distribution is far more rational than the one first given, and is certainly to be preferred. Rejection need not be applied where the method of determining particle size is to be employed only for routine purposes.

(II) 5. With glass lenses and white light, particles as small as 0.30μ will appear *clear*, centred with a black outline or circumference. Those a little less than this in diameter, however, will give for their image a *solid* black dot, resembling on the negative, in appearance and size, the diffraction disks produced by particles very much smaller.

There is consequently a limit, governed by the particle size, below which the method of measurement, described in this paper, is no longer applicable. Recourse must be had then to the use of ultra-violet light and quartz lenses, if we are to measure with reasonable accuracy pigments less than 0.30μ in diameter. Fortunately, for the method, pigments finer than this are exceptionally rare.

(II) 6. F. E. Ross has shown that tanning developers, such as pyro-elon and caustic hydroquinone, cause, upon the drying of the negative, contraction of the image. If it is found necessary to use these developers it is perhaps better to make measurements on the wet negative, care being taken that the heat of the stereopticon does not harm the gelatin emulsion in any way.

WHAT IS MEANT BY "PARTICLE SIZE."

We can speak definitely of the "diameter" of a sphere. If we have, say, a pound of fine spherical shot, each shot equal in regard to volume, then if the diameter of one shot is known it can be stated that the length of this diameter is the "particle size" of the entire one pound of material.

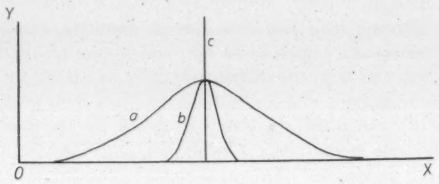
However, in the case of paint and rubber pigments we are dealing neither with spheres nor a perfectly uniform substance, hence the meaning of particle size is less definite here than in the previous illustration.

As pointed out, it is convenient to take as the "diameter"

of a particle that dimension which bears to specific surface the simple relationship shown in equation I. With this much established, let us examine further the significance of the expression "particle size."

If it is stated that the particle size of a sample of zinc oxide is 0.52μ, then it is meant that this is the diameter of the *average* particle. Such a fact may be used to determine specific surface, but aside from this it gives but a poor visualization of the texture of the material, for it neither discloses whether the oxide is composed entirely of particles 0.52μ in diameter nor whether it is a

FIG. 5.



Frequency curves for two pigments of the same average particle size but possessing different uniformities. Under the microscope, pigment *a* will appear to have a greater average diameter than *b*.

mixture ranging from ultramicroscopic particles to grains as coarse as sand and averaging 0.52μ.

This difficulty can be overcome in the following manner: *The Coefficient of Uniformity:* If we have two different pigments giving frequency distribution *a* and *b* (Fig. 5), it would be natural to decide, after a simple comparison under the microscope, that material *a* is the coarser of the two, yet upon actual measurement it will be shown that both pigments have the same average particle size. The reason for this misjudgment is due to the fact that material *a* contains some very large particle which are quite easy to see and consequently attract the eye, while the smaller ones, which it also contains, are difficult to find, and likely to be overlooked.

If this difference between *a* and *b* could be stated mathematically, then such an expression, together with the average diameter, would *completely* express the "particle size" of any given pigment. Fortunately this is quite possible to do, with a fair degree of success.

No doubt the reader has realized that this difference between *a* and *b* is simply one of degree of uniformity and that *b* is the more uniform of the two; and also that the "broader" the curve

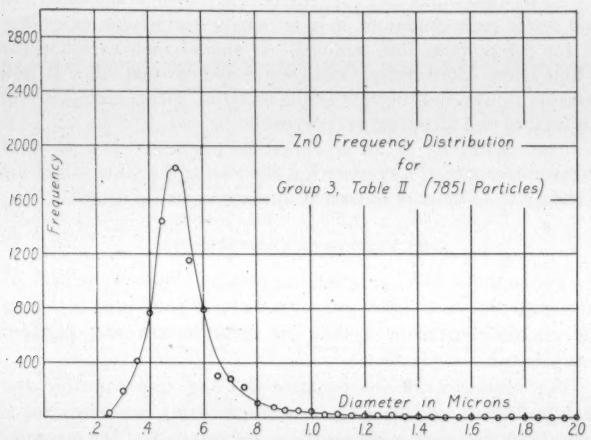
the less uniform the material. This characteristic is governed by the so-called "precision" coefficient, but here it will be referred to as the *uniformity* coefficient and designated by the letter U thus:

$$y = ce^{-U^2(x-a)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(XII)}$$

where c is the maximum value of y and a is the diameter of the average particle.

If all the particles of a pigment were equal in diameter, then

FIG. 6.



Frequency distribution for an average grade of zinc oxide. The measurements were taken from the 30 negatives recorded in Table II.

their frequency curve would be the straight verticle line c (Fig. 5); the uniformity would be perfect and U equal to infinity. Similarly, if no two particles were the same, U would become zero and the curve found to coincide with the x axis.

In practice, U is determined from the following equation:

$$U = \Delta x \sqrt{\frac{n}{2\Sigma v^2}} \quad \ldots\ldots\ldots\ldots\ldots \text{(XIII)}$$

where Δx is the difference between two consecutive values on

the x axis (*i.e.*, the millimetre axis) and should be made equal to unity for convenience; n is the number of particles measured and v the difference (in millimetres) between the particle and its average (at magnification, D, for convenience).

When the curve is symmetrical, U may be used, by substituting its value in equation XII, to find the percentage of any size particle present. This will give us a better idea of the nature of the material than the simple statement of the diameter of the average particle.

As the case sometimes happens, the curve will be asymmetrical, and under such conditions it is no longer permissible to employ U for the purpose just outlined. It should then be called the "Equivalent Uniformity Coefficient" and written U_e. It still remains, however, a constant of the material, and as such is useful for control and identification purposes.

The uniformity of an asymmetrical pigment [10] is equivalent to the uniformity of a symmetrical one having the same values for n and Σv^2 as those possessed by the asymmetrical material.

SOME RESULTS OF MEASUREMENTS.

The author's chief interest has been in the measurement of zinc oxide; hence in deciding upon a material to be used in testing the photomicrographic method of measurement this pigment was selected.

For routine work one negative showing approximately 250 particles [11] will usually give results sufficiently accurate; for a critical test, however, more negatives are required. The measurements presented below are the results of a far more extensive investigation than is ever likely to be found necessary in practice.

Five different bags of the same make of zinc oxide were sampled. Three mounts were made from each sample. Two photomicrographs were taken from each mount, giving a total in all of 30 negatives. The number of particles measured was 7851, and the time of measurement seven hours.

The measurements are given in Table II, in groups of 200-

[10] One giving an asymmetrical frequency curve.

[11] This does not include the marginal particles which are distorted and out of focus.

TABLE II.

Results of Measurements on 30 Negatives in Groups of 200–250, 1200–1500 and 7851 Particles.

	200–250 Particles			*1200–1500 Particles.*			*7851 Particles.*		
	Av. Diam.	Prob. Error	Unif. Coef.*	Ave. Diam.	Prob. Error	Unif. Coef.	Ave. Diam.	Prob. Error	Unif. Coef.
	First Negatives.			*1st 5 Negatives Combined in 1 Curve.*					
1A	.595	±.007	.207						
2A	.549	.010	.161						
3A	.522	.007	.219	.543	±.004	.183	.5340	±.0013	.207
4A	.522	.005	.263						
5A	.538	.005	.257						
	Second Negatives.			*2nd 5 Negatives Combined in 1 Curve.*			*30 Negatives Combined in a Single Curve.*		
1A	.548	±.009	.163						
2A	.530	.010	.150						
3A	.562	.007	.226	.547	±.004	.185			
4A	.544	.006	.232						
5A	.538	.007	.216						
	First Negatives.			*1st 5 Negatives Combined in 1 Curve.*					
1B	.518	±.005	.320						
2B	.552	.008	.168						
3B	.522	.005	.309	.539	±.003	.223			
4B	.525	.005	.292						
5B	.560	.007	.238						

	Second Negatives.		
1B	.527	±.005	.287
2B	.496	.005	.339
3B	.522	.005	.296
4B	.501	.005	.273
5B	.543	.006	.291
	First Negatives.		
1C	.538	±.007	.203
2C	.531	.005	.270
3C	.532	.005	.271
4C	.556	.008	.186
5C	.504	.004	.354
	Second Negatives.		
1C	.520	±.006	.267
2C	.518	.004	.359
3C	.524	.007	.201
4C	.519	.006	.240
5C	.515	.005	.310

Av. Probable Error ±1.13%

Total Error, Including Error in Magnification ±1.37

* Strictly Speaking, U_e

2nd 5 Negatives Combined in 1 Curve.

.515 ±.003 .261

1st 5 Negatives Combined in 1 Curve.

.533 ±.003 .223

2nd 5 Negatives Combined in 1 Curve.

.520 ±.003 .240

Av. Probable Error ±.56%

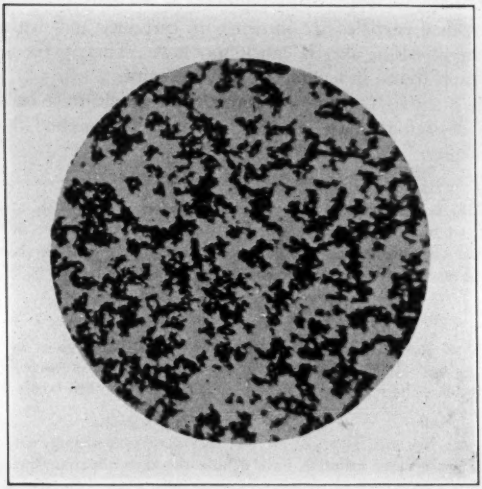
Total Error, Including Error in Magnification ±.96.

Av. Probable Error ±.24%

Total Error, Including Error in Magnification ±.82%

250, 1200–1500, and 7851 particles. The probable errors shown in the columns are due to the fact that the average diameter is derived from a finite number of particles. These errors are calculated from equation IX. The "total errors," given at the foot of the columns, include the errors in magnification and are derived from equation XI.

FIG. 7.



Timinox, 250 Diameters.

This is the type of pigment photomicrograph commonly found in the literature on paint. It is *not* suitable for particle measurement. The magnification and resolving power, under which the photomicrograph was taken, were both very much too low. It is impossible to detect individual particles. In addition the pigment is not dispersed.

Rejection, discussed under section $(II)_3$, was applied in each individual case. As particles which would be rejected in a small group of 250 would probably be retained in the two larger groups, the values in these latter ones were recalculated each time, that is, the average diameter, .543μ, given in the second group, for instance, is not necessarily the average of the first five diameters, shown in the first group, etc.

The groups are progressive and show the increase in accuracy and reliability with increasing number of measurements.[12]

In Table III are presented the results on the measurements of a variety of the most generally used pigments in the paint and rubber industries. Lamp black and gas black are omitted, however, as it has been impossible to secure negatives of these materials that were sufficiently satisfactory for measurement.[13]

Fig. 7 is the type of photomicrograph which is worthless for particle measurements. The pigments is not only flocculated but no individual particles are shown with certainty and distinctness. The magnification also is much too low. This is the kind of photograph found in technical books on paint.

Fig. 8 shows the type of photograph which must be secured if it is desired to make measurements by the method described in this paper.

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[12] If the uniformity of a material is known, then it is possible to calculate before hand just how many particles it is necessary to measure in order to reduce the probable error to any desired amount. If n is the number of measurements required and P_a the desired probable error, then,

$$n = \left(\frac{.4769\triangle x}{U\,P_A}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(XIV)}$$

If D = 20,000, then $\Delta x = 1/20{,}000$ mm. As P_A is given in microns, Δx will be .05μ. It must be noted that P_A is not the *total* probable error, *i.e.*, it only includes the error given in section (II) 1. All other errors are independent of n.

[13] It may be stated as a general fact that most technologists who have to deal with fine grained materials have neither the knowledge nor the technique necessary to enable them to make a successful microscopic examination of their products; hence many guesses, far from the truth, have often been given out as to the absolute and relative sizes of pigments. The author has had samples of materials presented to him by technologists who claimed that they were substances too fine to be seen with the microscope, yet in some cases the lowest power objectives were sufficient to resolve them into individual particles. In the case af gas black we are dealing with the finest grained material met with in the paint and rubber industries and, therefore, it is doubtful if there are many technologists capable of handling a pigment of this kind. In all probability the gas black particles are not colloidal, *i.e.*, less than 0.10μ in diameter. They are translucent and are of a brownish gray color. Their size lies most likely between 0.10μ and 0.20μ. This estimate does not take into consideration the very large particles of adamantine which all gas blacks contain.

TABLE III*

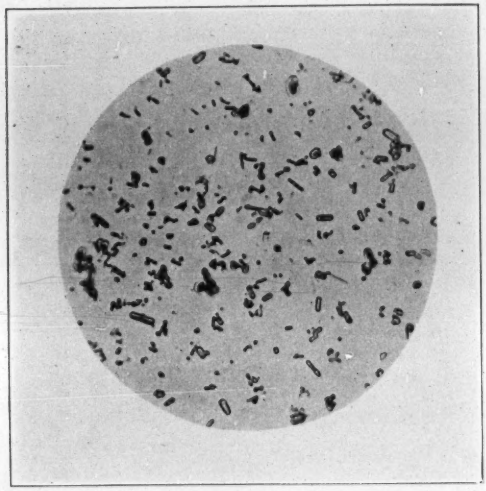
Name	Type	Sample	Negative	Diameter	U
Zinc Oxide	French Process	A		.36	
		B		.39	
		B		.40	
		C		.44	
Zinc Oxide	American Process	A		.46	
		B		.42	
		C		.46	
		D		.42	
		E		.42	
		F		.48	
		G		.46	
		H		.48	
		I	1	.46	
			2	.48	
		J	1	.40	
			2	.38	
Lithopone		A		.33	
		B		.38	
		C		.38	
		D	1	.40	
			2	.37	
			3	.40	
		E	1	.32	
			2	.36	
		F		.50	.210
Iron Oxide	Unadulterated	A		.43	.245
		B		.46	.351
		C		.54	.368
		D		.51	.230
		E		.58	.263
		F		.44	.188
Sublimed White Lead		A		.67	.132
		B		.65	.119
Basic Carbonate of Lead	Carter Process	A		1.03	.067
Basic Carbonate of Lead	Old Dutch Process	A		.75	.086
		B		1.21	
Basic Carbonate of Lead	Mathewson Process	A		1.95	.032
		B		2.39	
Barytes		A		5.33	.045

*The measurements given in this table refer to the average individual particle and do not take into consideration undispersed aggregates.

CONCLUSION.

Those who have devoted much time to the study of particle size will realize that fine-grained materials are of three types, and that each type requires a different method of attack in order to secure particle measurement.

FIG. 8.



Low Leaded Zinc Oxide, 1500 Diameters.

This photomicrograph is well suited for measurement. The crystalline outlines of a number of the particles are clearly shown.

Type A.—Colloidal partcles.

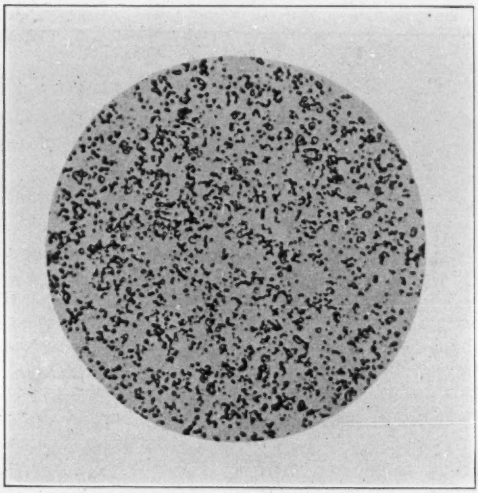
Type B.—Fumed products and fine precipitates such as zinc oxide and lithopone, etc. This type comprises the paint and rubber pigments.

Type C.—Clays and ground materials such as barytes, asbestine, etc. This type includes the so-called "inerts."

A number of methods have been developed for the measurement of colloidal particles. The photomicrographic method is not applicable to this type and therefore it will not be discussed here.

It is hardly necessary to state that the photomicrographic method has been developed expressly for the measurement of particles included under Type B. If applied to any other type it will not be found satisfactory, at least not without special treatment of the sample.

FIG. 9.



French Process Zinc Oxide, 1500 Diameters.

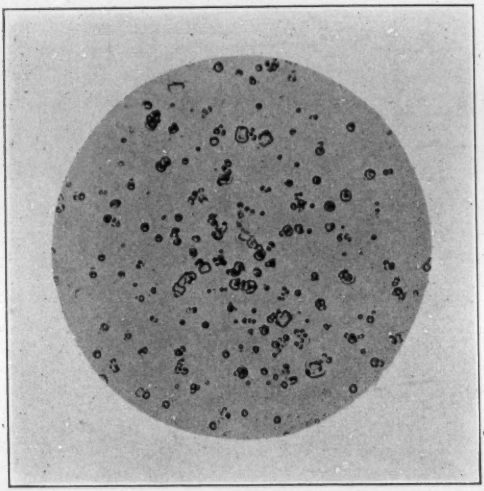
This particular sample of French Process Zinc Oxide approaches the limit of fineness to which the photomicrographic method is applicable: To go below this will require quartz lenses and ultra-violet light.

It seems to the author that the method of grain size determination by the use of a Zeiss-Thoma Counting Chamber employed by Curt Kühn [14] is ideally suitable for Type C, and not for Type B, as Curt Kühn himself uses it. This method necessitates the use of an objective of long working distance giving both low resolving power and magnification. Experience will soon convince one that under such conditions a large percentage of Type B pigment will escape notice altogether and in addition it

[14] *Zeitschrift für Angewandte Chemie*, March 16, 1915.

will not be possible to decide whether flocculates composed of two or three grains are single particles or not. Evidently some such state of affairs did occur for Curt Kühn gives his finest grained lithopone as 372 billion particles [15] per gram, whereas for a lithopone as coarse as 0.40μ and density 4.30, there will be found to be no less than 6850 billion per gram. Similarly for

FIG. 10.



Sublimed White Lead, 1500 Diameters.
A good photomicrograph for measurement.

iron oxide, Curt Kühn gives 308 billion, while this pigment, even when as coarse as 0.50μ and with a density of 5.15, will have 2980 billion per gram. Also with lamp black; here his result is 960 billion as against 19,000 billion, assuming the lamp black particle to be as large as 0.40μ (and it is doubtful if it even attains so large a size). From these facts it does not seem advisable to recommend Curt Kühn's method for Type B pigments.

[15] Particles assumed to be spherical and $U = \infty$.

TABLE IV.*

Showing Relationship of Diameter, Specific Surface, Number of Particles per Gram and Mass of Particle for Zinc Oxide.

Dia. in Microns. μ	Specific Surface in Sq. Meters	Number of Particles per gram, in Trillions	Mass of Particle in Grams
0.70	1.48	.96	1.045×10^{-12}
0.60	1.73	1.54	$.650 \times 10^{-12}$
0.50	2.08	2.64	$.379 \times 10^{-12}$
0.40	2.60	5.17	$.193 \times 10^{-12}$
0.30	3.46	12.24	$.082 \times 10^{-12}$
0.20	5.20	41.40	$.024 \times 10^{-12}$
0.10	10.38	331.20	$.003 \times 10^{-12}$

Specific Surface, surface per gram of material, (S).

Number of particles per gram $= \frac{S}{\pi \mu 2}$ trillion $= n$.

Mass of 1 particle $= \frac{1}{n} \times 10^{-12}$ grams.

* Particles assumed to be spherical and $U = \infty$.

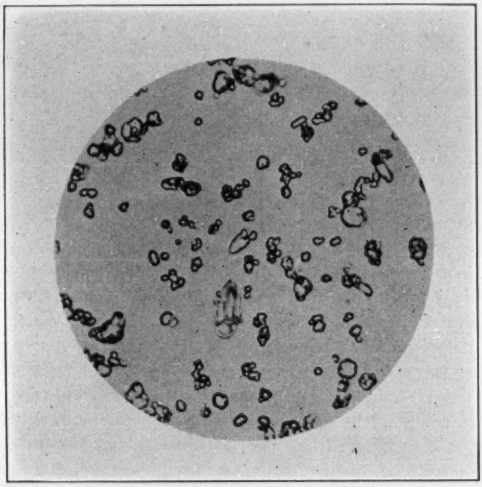
The foregoing paragraphs will probably suggest the question, that if increasing the magnification (550 diameters) employed in the Zeiss-Thoma Chamber method to that used by the photomicrographic method, reveals finer particles and distinguishes between flocculates and individual grains, how do we know that a further increase in microscopic efficiency would not again produce similar results? The answer will depend entirely on the nature of the material examined. For pigments, just on the border line of resolvability, half the particles produce so much defraction that a measurement of their size depends more on an estimate of the intensity of their image than anything else, and hence an increase of resolving becomes a necessity if we desire an accurate measurement of this pigment.

On the other hand, pigments as coarse as .50μ would probably reveal nothing further. This is apparent from the sharp declivity of the left-hand branch of the probability curve. (See Fig. 6.) In this case the number of particles not revealed on the negative is negligible. If this branch of the curve follows the probability law, *then it is always possible to calculate the theoretical number of particles missing,* and so further increase the range over which the photomicrographic method is applicable.

The question has often been asked, how is it possible to know,

upon examining a pigment under the microscope, whether one really sees individual particles or simply aggregates? There are a number of ways of deciding upon this. First, most pigments are crystalline, and if it is possible to see the crystal outlines, even if only a relatively few particles, it is reasonable to believe that the remaining portion of the pigment is of the same order of

FIG. 11.



Old Dutch Corroded White Lead, 1500 Diameters.

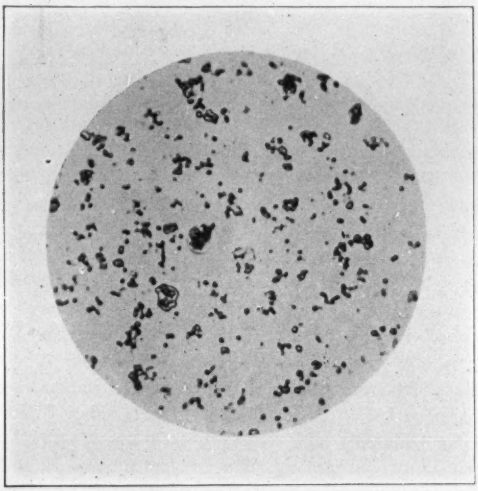
Even though this material is badly flocculated the clear outlines of most of the particles are sufficiently well shown so as to make possible a successful measurement.

magnitude and what we are able to see, therefore, must be, in general, individual particle. Secondly, an individual particle by transmitted light should and does look *clear* and *transparent*, except of course at its boundary, which appears black. Under transmitted light aggregates are always black, regardless of their color. (See Fig. 7.) Thirdly, individual particles in a number of pigments will show a *uniform extinction of their entire face*, when rotated between crossed nicols. Aggregates do not extinguish uniformly on account of the fact that the individ-

ual grains of which they are composed are differently orientated with respect to their optic axis.

In conclusion the author wishes to acknowledge his indebtedness to Mr. Roger Graver for his assistance in producing the many excellent negatives required for this work, and to Mr. Arthur F. Frantz for his assistance with the innumerable computations that were demanded in the preparation of this paper.

FIG. 12.



Pure Iron Oxide, 1500 Diameters.

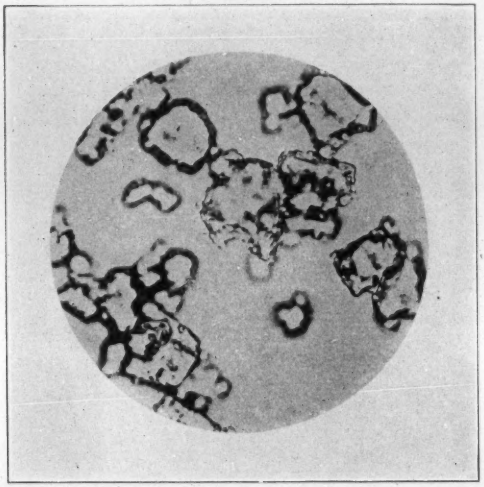
As some of the smallest particles shown here are seen to be "clear centered," it is therefore demonstrated that the resolving power and magnification of the microscope are sufficient to show the individual grains of this pigment. On account of this fact the very smallest particles, appearing to be dark centered, are also in all probability individual particles.

SUMMARY.

1. A method of determining the "diameter" of paint and rubber pigments, by first taking a photomicrograph of the sample, at a carefully ascertained magnification, and secondly again enlarging by means of a stereopticon and then measuring the particles on the projecting screen, is described. It comprises:

(a) The method of dispersing and mounting the pigment so as to make it suitable for photomicroscopy.
(b) The method of determining the magnification of the microscope and stereopticon.
(c) The method of measurement.

FIG. 13.



Barytes, 1500 Diameters.

On account of the low uniformity of barytes it would take about 20 times the number of particles shown here in order to make a successful particle measurement of it.

(d) The calculation of the probable error.
(e) The determination of the uniformity coefficient.

2. The meaning of "particle size" is discussed. That dimension which bears the simplest relationship to specific surface has been selected as the "diameter" of the particle.

3. The results of the measurements of various pigments are given in tables.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE PRODUCTION OF LIQUID AIR ON A LABORATORY SCALE.[1]

[ABSTRACT.]

THE essentials of a plant producing liquid air by the Hampson process are the compressor, purifying train and liquefier. The compressor, usually of four stages, delivers air at room temperature and approximately 3000 pounds per square inch. The compressed air purifying train consists of first, a trap for receiving oil and water, and secondly, suitable containers which are charged with chemical reagents, such as sodium hydroxide, calcium chloride, or lime, for removing carbon dioxide and water vapor. The air thus compressed and purified is delivered to the liquefier, in which, after passing through a coil of copper tubing, the air is allowed to expand freely to approximately atmospheric pressure. Where this drop in pressure takes place there is a corresponding drop in the temperature of the air. The expanded air before leaving the liquefier is caused to circulate around the copper coil which contains the compressed air thus cooling the coil and in turn the compressed air so that on continuous operation a cycle of progressive cooling is maintained until the temperature ultimately reaches the liquefying point. The liquefier is so constructed that the air which is condensed to liquid is delivered into a receiving vessel. The gaseous air exhausted from the liquefier is returned to the intake of the compressor for succeeding cycles because it has been purified and when used repeatedly will be less exhausting on the purifying reagents.

* Communicated by the Director.

[1] Scientific Paper No. 419.

THE CEMENTING QUALITIES OF THE CALCIUM ALUMINATES.[2]

By P. H. Bates.

[ABSTRACT.]

THE four calcium aluminates, $3CaO.Al_2O_3$, $5CaO.3Al_2O_3$, $CaO.Al_2O_3$, and $3CaO.5Al_2O_3$, which are the only anhydrous compounds of lime and alumina, were prepared in a pure condition by heating together the proper proportion of these compounds. After microscopic examination had shown that homogenous compounds had been formed, the products were finely ground and their cementing qualities when gaged with water were determined.

The two compounds higher in lime reacted very energetically with the evolution of much heat, acquiring practically instantaneous set. The two compounds higher in alumina reacted with water more like Portland cement, but showed higher strength at earlier periods than the latter. It was thought desirable therefore to prepare these in larger quantities and containing such impurities as silica, iron oxide, and magnesia, which would generally be present in lime and alumina of natural origin. The two compounds $CaO.Al_2O_3$ and $3CaO.5Al_2O_3$ were consequently burned in a 2 by 20 foot rotary kiln, varying their composition so that the silica, iron oxide, and magnesia reached limits of 17.38, 3.10, and 3.66 per cent., respectively, as maxima in a series of eight cements. The process of manufacture was entirely similar to that used in the production of Portland cement.

The ground cements were used in making the usual small tension and compressive test pieces and 6 by 12 in. gravel concrete cylinders of 1 : 1.5 : 4.5 and 1 : 3 : 9 proportions. The striking feature of the data obtained from testing these at different periods up to and including three years was the very high 24-hour strength. The rich concretes prepared from four of the cements developed in 24 hours strengths in excess of 2800 pounds per square inch, and the lead concretes from two of the cements gave strengths beyond 1500 lb. at the same period. Consistent gain in strength was obtained up to one year, when one of the cements in the rich concrete gave a strength of 8220 pounds per square inch.

[2] Technologic Paper No. 197.

Test pieces stored in water tended to show retrogression in strength with age. This was also noted with test pieces stored in the damp closet, but to a much less degree. This action may be explained by the fact that the products of the hydration of all the aluminates are a hydrated $3CaO.Al_2O_3$ and hydrated alumina (except in the case of the anhydrous $3CaO.Al_2O_3$, when no hydrated alumina is produced). This latter is the cementing agent in these products, and, being colloidal, it is very susceptible to moisture changes. Large amounts of moisture are taken up in the presence of the latter with consequent swelling of the colloid and reduction in strength.

HOW TO GET BETTER SERVICE WITH LESS NATURAL GAS IN DOMESTIC GAS APPLIANCES.[3]

[ABSTRACT.]

THIS paper gives the principal conclusions from the laboratory and field investigations of the Bureau on the correct use of natural gas in the home. It is estimated that it would take a million dollars worth of artificial gas each day to replace the waste in natural gas appliances, and it is certain that unless this waste is halted, it will be but a short time when most of the more than two thousand small communities depending on natural gas will have to go back to solid fuel with its many inconveniences, since most of them are not large enough to maintain manufactured plants.

About one-half of the cities in the United States have natural gas, and the consumers number over two and one-half million.

Most of the natural gas stoves have the burners placed two and one-half inches or more below the top of the grid or the solid top which many of them have. This has made it necessary to burn a large volume of gas, supplied with a high pressure and has resulted in a great waste of gas, and very poor service during the winter when the pressure happened to be low.

Tests have shown that by removing the solid top and raising the burners close to the vessel, it is possible to reduce the gas consumption to one-fourth that required with the low set, solid top stoves, and also to improve the service very much.

[3] Circular No. 116.

Other advantages from these changes in the appliances will be the great reduction in the leakage with the reduction in the gas pressure in the distributing systems. Two ounces and even less are sufficient for good service, whereas it has been thought that four ounces were necessary. The loss in leakage at four ounces is approximately forty per cent. greater than it is at two ounces.

The lower the minimum pressure at which the gas companies are allowed to supply the gas to consumers the easier it is for the company to maintain satisfactory pressure conditions. In many cases the line pressure is quite sufficient to give good service, but it is not properly utilized, due to the poor design of the burner and burner orifice, and dirty burners.

THE TESTING OF RUBBER GOODS.[1]

THE purpose of this circular is to describe the methods of physical and chemical testing used at the Bureau of Standards.

An introductory portion gives information about crude rubber and the manufacture of rubber goods. The sources of crude rubber are briefly described, as well as the methods of collection and preparation.

The materials used in the compounding of rubber are classified as follows: Reclaimed rubber, rubber substitutes, vulcanizing and compounding ingredients. The latter are divided into inorganic and organic fillers, inorganic and organic accelerators, and pigments.

The various processes which are common to all branches of the rubber industry are described. These are the washing and drying of the crude rubbers, the compounding or mixing of rubber and ingredients, the calendering and vulcanizing of rubber compounds accompanying the above, illustrations of the experimental equipment used at the Bureau, which represent on a small scale typical rubber machinery.

A brief summary is included of the essential details of the manufacture of pneumatic tires, solid tires, inner tubes, mechanical goods, such as hose, belting, and tubing, and druggists' sundries, such as hot-water bottles and rubber bands.

[1] Circular No. 38.

The methods of physical testing are described in detail. Complete data are given of the results of the experimental work that has been carried on at the Bureau. These investigations were made to determine the effect on the tensile strength, ultimate elongation, and recovery of a rubber compound by varying the conditions under which the tests are made. Some of these conditions are: The rate at which the specimen is stretched, the temperature, the cross section of the test specimen, the direction in which the test specimen is cut, and the shape of the test specimen.

The comparison of the tensile strength and ultimate elongation of twelve compounds that were aged for varying periods at $158 \pm 2°$ F., in an electric oven, and under ordinary conditions of storage extending over a period of 7 years, are graphically shown.

The methods of chemical analysis are described in detail and include not only the usual methods for the determination of the acetone, chloroform, and alcoholic-soda extracts, free and total sulphur, ash and sulphur in ash, but also those for the determination of barytes, barium carbonate, glue, rubber by combustion of the introsite, total fillers, antimony, cork, leather, wood, and vegetable fibres and cellulose.

The methods adopted by the Joint Rubber Insulation Committee for the analysis of rubber covered wire has been incorporated.

The methods of testing fabrics used in the manufacture of rubber goods are described.

The appendix contains a list of governmental specifications drawn up by the Bureau; a bibliography of the papers published by the Bureau, and of the more important books and periodicals that deal with rubber, and a table of the specific gravities of the most common compounding ingredients used.

PRECISION TEST OF LARGE CAPACITY SCALES.[1]

By C. A. Briggs and E. D. Gordon.

[ABSTRACT.]

THE accuracy that can be obtained from large weighing scales is not generally known among engineers and others concerned in the subject. This paper outlines a scientific and systematic procedure for the accurate test of large capacity compound lever

[1] Technologic Paper No. 199.

scales, by a method which has been developed and used by the Bureau of Standards, largely in connection with its work in testing railroad master track scales, and grain hopper scales; but the plan can be adapted to the test of almost any compound lever scale.

A pointer and graduated scale are arranged for reading the position of the beam; and the errors of the scale are determined from observations made upon the beam while it swings freely. The method of recording data and of determining the results is very similar to that which has been in use in laboratories for precision weighings on fine equal-arm balances. The method of taking and recording the data also tends to eliminate the personal equation, to point out where mistakes are made, when such occur, and give a very complete record of the test which will present very understandable and detailed information to anyone who has occasion to make a critical study of the test.

The method is not suggested for use in the regular routine testing of ordinary compound lever scales, where precision results are not required. The method given here requires the observance of certain details consistent with realizing precision, and requires training and ability to a greater extent in those making the test than is required in the ordinary case.

The procedure of the test is explained with the aid of a record form and computation sheet which was developed in connection with the successful application of the method in the field. In the interest of a uniform and efficient method the scheme outlined is recommended to those who have occasion to carry out tests on large scales where accuracy of a high order is required.

RESULTS OF A SURVEY OF ELEVATOR INTERLOCKS AND AN ANALYSIS OF ELEVATOR ACCIDENT STATISTICS.[6]

By C. E. Oakes and J. A. Dickinson.

[ABSTRACT.]

THIS report gives the results of a field survey of several thousand elevator landings equipped with various types of mechanical and electromechanical interlocks and contact devices. This survey was carried out in connection with the preparation of an Elevator Safety Code, in which work the Bureau engineers have coöperated with the American Society of Mechanical Engineers.

[6] Technologic Paper No. 202.

The elevators are classified into three groups: Class A, elevators located in buildings in which the service is heavy and where maintenance service is provided; Class B, buildings in which the service is heavy, but where no maintenance service is provided; and Class C, buildings in which the service is light and in which no maintenance service is provided.

The data which were secured in various parts of three states and a number of large cities, are classified under the above grouping, the performance in each group being briefly discussed.

The difference between an electromechanical interlock and a contact device is clearly pointed out and the functions and usual method of operation of each type of device is given.

The comparison of advantages and disadvantages and a comparison of service of each of the three types are given in tabular form. Some suggestions as to possible improvement are added.

Representative statistics of elevator accidents are given: Group I.—Accidents from the entire United States reported by the public press through clipping bureau; Group II.—Industrial elevator accidents reported by various state departments of labor or state industrial boards (these accidents cover employees only); Group III.—Accidents to the public and employees reported by the coroners' offices or elevator inspection departments of large cities.

These statistics have all been reclassified as non-shaft-door and shaft-door accidents, the latter being those that should be eliminated by the use of interlocking devices.

A table of weighted averages of all the statistics is added and shows that 73.8 per cent. of all fatal accidents would probably be eliminated by the use of well-designed interlocks.

The report quotes the A. S. M. E. Elevator Code specifications for interlocks in conclusion.

Electric Furnace Treatment of Nickel-silver.—Among the alloys for which the electric furnace treatment seems best is nickel-silver, as pointed out in a paper by Thompson, presented to the American Electrochemical Society at its last (fortieth) meeting. The specific advantages observed here are: The loss of zinc is less than 1 per cent., the occulsion of gases is minimized, a tougher alloy with less carbonization is obtained. Figures are given showing the avidity with which the alloy will absorb carbon from a graphite crucible as contrasted with one of clay. Thompson also states that in his opinion the electric furnace has

advantages when large quantities of scrap are to be remelted, in minimizing the accumulation of sulphur and carbon, and thus reducing the amount of virgin metal required for the charge.

H. L.

The Age of the Earth.—This question was the subject of a formal discussion at the recent meeting of the British Association for the Advancement of Science. Lord Rayleigh made the opening remarks, reviewing the methods that have been proposed. Lord Kelvin's calculations based on a limit of the sun's heat and the internal heat of the earth have been upset by the discovery of radioactivity. Lord Kelvin gave but a limited duration to the period in which the earth was cool enough to support the life that is now on it, a result which was not acceptable to many geologists and paleontologists, who believed that the evidence of the fossil remains indicated a much longer period. Darwin termed Kelvin's result "an odious spectre."

The changes undergone by uranium have been recently made the basis of calculation, and especially the accumulation of lead in uranium-containing minerals. The upshot of the calculations at hand is a moderate multiple of one billion years as the time during which the earth was suitable for living beings, and data from physics or astronomy afford no definite presumption against this view. Rayleigh waives any discussion of the biologic and geologic data.

J. W. Gregory says that the best-known geologic estimates require to be multiplied ten or twenty-fold in order to agree with the physical estimates. A. S. Eddington suggests that Lord Kelvin's time-scale should be lengthened five-hundred-fold, at least during the stage of evolution. Gregory makes a curious mistake in saying that the claim that geologic time covered only a few score million years was regarded by geologists as of little more use than the "seven days of the Pentateuch." The creation, however, is given in the Pentateuch as having taken only six days.

H. L.

Electrolytic Corrosion of Lead-Thallium Alloys.—Fink and Eldridge in a communication to the recent (fortieth) meeting of the American Electrochemical Society report experiments undertaken with a view to minimize the loss of metal in anodes used in procedures of copper precipitation in Chile. It was found that an alloy of 70 per cent. lead, 20 per cent. tin and 10 per cent. thallium lost only 1.2 pounds per 100 pounds of copper precipitated. It was also found that, in general, alloys with high melting points are more resistant to corrosion. The liquid subjected to electrolysis in the operations studied was a solution of copper sulphate containing nitric and hydrochloric acids. The low corrosion is due to a strongly adherent film formed on the anode.

H. L.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

THE GOLD NUMBER OF COMMERCIAL GELATINES.[1]

By Felix A. Elliott and S. E. Sheppard.

ZSIGMONDY'S method for the preparation of deep red, highly homogeneous, gold hydrosols was modified to the extent that a dilute solution of formaldehyde is added very slowly with thorough stirring until the first color appears. Further amounts were then added by drops until no further change in color took place. The protective action was measured by the amount of gelatine, expressed in milligrams, just necessary to prevent the change in color of 10 cc. of the standard gold solution. Seventeen different gelatines of all grades representing all methods of manufacture were shown to differ but little in their protective action. The classification thus made possible is too rough and, moreover, does not bear any simple relation to those properties of gelatine of chief interest to users of gelatines.

It has been shown that the gold number increases as the concentration decreases, and that it increases the longer the gelatine solution stands or "ages" after it has been made.

The effect of making the gelatines solutions under different conditions was investigated, and it was found that the more dilute the solutions made up the lower the gold number. Subsequent dilution at ordinary temperatures does not change this conclusion.

The state of subdivision of gelatine solutions was very definitely indicated by these gold numbers and confirmed by ultramicroscopic observations. These solutions were shown to contain varying proportions of large and small particles, depending on the temperature at which they were in equilibrium, there being a predominance of large particles at lower temperatures.

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* Communicated by the Director.

[1] Communication No. 118 from the Research Laboratory, Eastman Kodak Company and published in the *Journ. Ind. and Eng. Chem.*, Aug., 1921, p. 699.

THE ABSORPTION OF LIGHT BY TONED AND TINTED MOTION PICTURE FILM.[2]

By L. A. Jones and C. W. Gibbs.

IN order to measure precisely the absorption of light by toned and tinted motion picture film, a special instrument was designed and constructed. The optical system of this instrument is so arranged that the transmission value measured is that of the effective transmission of the picture as projected in the standard motion picture machine. Since such a picture is composed of silver deposits which are diffuse in nature, that is, light scattering, they must, in order to obtain the value of effective projection transmission, be illuminated under precisely the same conditions as exist in the projecting machine. Furthermore, since in dealing with toned and tinted film, color differences are involved, it was necessary to use a flicker method for measuring the desired values of transmission. The apparatus constructed for this work is therefore called an "integrating flicker photometer," and measures the mean effective projection transmission of the sample under consideration.

The results obtained in the case of tinted pictures show that the tinting process produces no change in the physical contrast of the picture but merely decreases the transmission. The transmission values for the series of colors examined varied from 26 per cent. in the case of cine violet to 82 per cent. in the case of cine yellow. The results obtained with the dye tone samples show that the decrease in transmission is not directly proportional to the density of the deposit, but that the deposits of higher density are more affected by the treatment than the very low densities. This tends to produce a slight increase in the physical contrast of the picture. The selective action, however, is confined largely to the densities lying on the toe of the curve, which results in a lengthening of the straight line portion of the curve without materially changing the slope of the straight line portion. The transmission values for a series of dye toned samples vary from 43 per cent. for the safranine to 89 per cent. for one of the auramine tones. These values are relative to the transmission of the untoned sample. In the chemical toned samples, the selective intensification is much

[2] Communication No. 122 from the Research Laboratory of the Eastman Kodak Company and published in *Trans. Soc. Mot. Pic. Eng.*, No. 12, p. 85.

more marked, the results being an almost complete straightening out of the unexposed region of the curve. This produces a material increase in the physical contrast and a better tone rendering of the negatives. The values vary from 46 per cent. for the uranium to 69 per cent. for the sulphide tone. On account of its integrating character, the apparatus is adapted to measure the mean transmission of a sample consisting of an uneven distribution of density such as occurs in a cine picture. A large number of pictures representing as nearly as possible the entire range of subjects met with in this work were selected and mean transmission values determined. The results on a group of forty-one samples show an average mean transmission value of 14.59, the mean transmission varying from a minimum of 3.2 per cent. to a maximum of 38.8 per cent.

A New Process for the Recovery of Silver from Fixing Baths. —The silver which is not in the finished picture is almost entirely in the fixing solution. The developer and wash waters contain mere traces, probably mechanically detached from the film. In large scale work the dissolved silver is regularly recovered, and, as the ordinary precipitant for silver, sodium chloride, does not affect the hypo-solution, sodium sulphide is often used, which forms an insoluble sulphide. Recently a German chemist has recommended a compound known commonly as sodium hydrosulphite, which is a powerful reducing agent and throws down metallic silver from the solution in the fixing bath. This compound has industrial application along several lines, considerable amounts being used in reducing indigo in the ordinary methods for dyeing with this color.

An unfortunate confusion in nomenclature of some of these compounds interferes with systematic discussion of their chemistry. The "hypo" of the photographer was at first thought to be the true hyposulphite, but is now known to be a derivative of sulphuric acid, and its correct name according to the modern system is "thiosulphate." The true sodium hyposulphite is Na_2SO_2, while the hypo of the photographer has the formula, $Na_2S_2O_3$. The substance mentioned above as a reducing agent is given the formula, $Na_2S_2O_4$, and receives the name "sodium hydrosulphite." It is not likely that the amateur will care to recover the silver from the fixing bath, but the procedure may be found advantageous for the worker on the large scale. After treatment of a fixing bath with sufficient of the precipitating agent, the bath is revived and may be used again.

H. L.

Problems in Physics. O. W. RICHARDSON. (*Science*, Sept. 30, 1921.)—This address of the distinguished vice-president of Section A of the British Association for the Advancement of Science was delivered at the recent Edinburgh meeting. It is notable not only for its scientific quality but also for its fine literary flavor. Let one instance suffice. "Relativity is the revolutionary movement in physics which has caught the public eye, perhaps because it deals with conceptions in a manner which for the most part is found pleasantly incomprehensible."

On the same subject, dealt with at the very beginning of the address, this is said, "My predecessor in office a year ago reminded you that the theoretical researches of Einstein and Weyl suggest that not merely the material universe but space itself is perhaps finite. As to the probabilities I do not wish to express an opinion; but the statement is significant of the extent of the revolution in the conceptions and fundamental principles of physics now in progress. That space need not be infinite has, I believe, long been recognized by geometricians, and appropriate geometries to meet its limitations have been devised by ingenious mathematicians. I doubt, however, whether these inventive gentlemen ever dreamed that their schemes held any objective validity such as would assist the astronomer and the physicist in understanding and classifying material phenomena. It is not certain that they will; but the possibility is definite. Apart from this, the whole development of relativity is an extraordinary triumph for pure mathematics. Had Einstein not found his entire calculus ready at hand, owing to the purely mathematical work of Christoffel, Riemann and others, it seems certain that the development of generalized relativity would have been much slower. It is a pleasure to be able to acknowledge this indebtedness of physics and astronomy to pure mathematics."

G. F. S.

Dissociations of Sodium and Calcium Cyanamide in Aqueous Solutions.—Naoto Kameyama has made studies on the subject. The growing importance of all nitrogen fixation methods gives to cyanamides practical interest. The communication is part of the results of work at the College of Engineering at Tokyo, and will appear in full in the journal of that institution. The brief account is part of the proceedings of the American Electrochemical Society. Sodium acid cyanamide is hydrolyzed in water-solution to the extent of 4.5 per cent. to 12.9 per cent. in certain dilutions. If the hydrolysis is prevented by an excess of the cyanamide, dissociation occurs to almost the same extent as in the case of sodium formate. Under similar conditions unhydrolyzed calcium acid cyanamide dissociates to the same extent as magnesium formate or calcium nitrate. The conductivity of the cyanamide anion was found to be about that of the formate anion.

H. L.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

BACTERIA IN SUGAR-CANE PRODUCTS.[1]

By Margaret B. Church.

[ABSTRACT.]

CONTAMINATING molds, yeasts, and bacteria gain entrance to sugar-cane products at the sugar house through the air, the mixer, and the spout when massecuite is allowed to accumulate for any length of time. Impure wash water at the centrifugals and open or unclean conveyors are responsible for similar contamination. Molasses was found to contain more microörganisms than wash. The separation of wash from molasses therefore would avail nothing except perhaps to render the molasses a more unfavorable medium for microbial life. The number of organisms in magma increases during storage. The results of an experiment with superheated steam at the centrifugal, parallel to that previously conducted at the Louisiana Experiment Station, indicated that superheated steam is useful in reducing actively growing organisms in sugar and molasses at the centrifugal. Home sugars, however, should be made in a sufficiently clean manner to make the use of superheated steam at the centrifugal unwarranted.

THE DETECTION AND ESTIMATION OF COAL-TAR OILS IN TURPENTINE.[2]

By V. E. Grotlisch and W. C. Smith.

[ABSTRACT.]

THE method outlined includes the following steps: (1) Passing dry hydrogen chloride gas into the liquid, thus converting the pinene into crystalline pinene hydrochloride, also raising the boiling points of the unprecipitated reaction products; (2) distillation of the filtrate under reduced pressure to separate the coal-tar oils

* Communicated by the Acting Chief of the Bureau.

[1] Published in *Sugar*, 23 (1921): 413, 491.

[2] Published in *J. Ind. Eng. Chem.*, 13 (1921): 791.

with a minimum of terpene bodies; (3) sulphonation of the distillate with fuming sulphuric acid, thereby destroying terpenes and converting coal-tar hydrocarbons into sulphonic acids; (4) dilution and steam distillation of the sulphonation mixture to remove undecomposed terpenes or mineral oils; (5) direct distillation of the sulphonation mixture to break up the sulphonic acids, with recovery of the coal-tar hydrocarbons.

After an interim of some years due to the war with Germany the journal *Physikalische Zeitschrift*, is again reaching the library of THE FRANKLIN INSTITUTE. On the last page of the number for July 15 of this year the reader is surprised to note in capital letters A.E.F. On examination, however, these are found to be the abbreviations not of American Expeditionary Force but of the name of a committee on units and constants. This particular article deals with the method of designating and reading certain vector quantities and Hamilton's operator Nabla.

Under "Personal Notes" one reads of the promotion of a professor of chemistry from the University of Arizona to the corresponding institution in Minnesota, of the appointment of a professor of chemistry to the Artillery College in England, and of another to the University of St. Andrew, Scotland. The death is announced of the former professor of physics at Vienna, Viktor von Lang.

A woman physicist who was graduated with distinction and has been an assistant in an institution of high grade seeks a position in industry—an indication of a tendency much in evidence in the United States in recent years.

S. Hirzel, of Leipzig, advertises a translation of Sir Ernest Rutherford's Bakerian lecture on the structure of the atomic nucleus, explaining that such translations are no longer as formerly a luxury for those who do not read foreign languages with ease but are "unfortunately a necessary Ersatz [Note the famous war-worn word for "substitute"] for foreign publications, often unattainable and generally exorbitant in price." The same firm presents to the public no less than three books dealing with the theory of relativity. Planck's quantum theory and the methods of measuring the enigmatic h form the subject of a fourth book advertised. Between the lines calling attention to Otto Wiener's "Principles of Flight" it is not difficult to read a bit of war history. What but this upheaval would have diverted the interest of the eminent investigator in the field of optics from his chosen pursuits?

G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

ZIRCONIUM.

By J. W. Marden and M. N. Rich.

ZIRCONIUM and its alloys or compounds are finding increasing use as an acid resistive metal, for electrodes, for armor and automobile steels, abrasives, pigments, mordants, insulators, fire brick, and other products.

Zircon is a widely distributed mineral, being found in workable quantities in the United States, Canada and Norway. In Brazil large deposits of brazilite are found. The Bureau of Mines has completed an extensive investigation regarding the properties and uses of metallic zirconium and its salts. The results are given in Bulletin 186, "Investigations of Zirconium with Especial Reference to the Metal and Oxide."

DETERMINATION OF OXIDES OF NITROGEN.

By V. C. Allison.

A NEW method for the determination of oxides of nitrogen has been developed in the Bureau of Mines laboratories, by means of which as low as ten parts of the gas in a million parts of air can be detected. Oxides of nitrogen are intensely poisonous gases, sometimes formed after blasting in mines, and are also developed in certain other industries. The method will be useful in determining ventilation conditions, and hazards from exposure of miners to gases liberated in blasting. The method is described in detail in Technical Paper 249, "The Determination of Oxides of Nitrogen," by V. C. Allison, W. L. Parker, and G. W. Jones.

HOT HIGH-NITROGEN GAS IN A METAL MINE.

By G. E. McElroy.

WHILE investigating the presence of heavy strata gases in certain mines of the East Tintic mining district of Utah, a small, local body of light, very hot gas of high-nitrogen composition was noted in one of the mines. Observations and analyses indicate that this light gas was resulting from very rapid oxidation of

* Communicated by the Director.

finely disseminated pyrite, in lead-silver sulphide ore. The gas was actually mine air which had lost a large proportion of its oxygen content by reaction with the pyrite. This body of gas was hanging in a local high spot caused by caving, in the end of a 5 by 7 foot cross-cut. Fifty feet distant an air current was entering from a raise from below.

Results of analyses for samples taken show that the gas is black damp composed almost wholly of nitrogen. One sample taken four feet above the vapor level and one foot below the roof had a temperature of 175.5° F., humidity 100 per cent., CO_2 .38, O_2 2.49, N_2 97.13 per cent., as reported. The calculated air-free black damp content was 88.10 per cent., composed of 0.42 per cent. CO_2 and 99.58 per cent. N_2.

That the process of oxidation was still in rapid progress was evidenced by the fact that, although the volume of the body of gas was practically constant, a thin stream of hot gas was flowing along the roof to the air current fifty feet away.

The gas had a strong, musty, sulphur odor and had a suffocating effect when breathed. Attempts to prove the presence of sulphuric acid vapor in the body of gas were not determinate, although a very slight amount was undoubtedly present. The presence of this body of gas in this particular mine probably represents the first step in the production of certain heavy strata gases high in carbon dioxide content that affect mines in this district, that is, the production of residual atmospheres by oxidation of sulphides, accompanied by the production of heat, sulphur dioxide and sulphuric acid, the succeeding step being the production of carbon dioxide by reaction of the acid with carbonates. Further details are given in a recent report issued by the Bureau of Mines in mimeograph form.

Chinese Leather.—According to LLOYD BALDERSTON (*Jour. Am. Leather Chem. Asso.*, 1921, xvi, 367–374), the Chinese obtain red leather by the use of mangrove bark as a tanning material. They manufacture white leather by tanning with alum, Glauber salt, (sodium sulphate), or smoke. In Manchuria, leather is tanned by the use of yogurt or fermented milk. In a few Chinese tanneries, leather is manufactured according to Western methods. In addition to the oaks, several species of native Japanese trees may serve as a source of tannin for the leather industry. Thus the bark of coniferous trees is a waste product of the paper pulp industry; yet the amount of this bark wasted yearly in Japan contains tannins worth approximately $100,000.

J. S. H.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, October 19, 1921.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, October 19, 1921.

VICE-PRESIDENT MR. COLEMAN SELLERS, JR., *in the Chair.*

Additions to membership, since last report, 14.

Reports of progress were presented by the Committee on Library and the Committee on Science and the Arts.

The Chairman then announced that the next business of the meeting would be the presentation of medals and certificates to gentlemen whose inventions had been examined by the Committee on Science and the Arts and found worthy of recognition by the Institute. He then recognized Dr. Harry F. Keller who introduced Dr. Byron E. Eldred, of New York City, recently awarded the Elliott Cresson Medal for his invention of "Low Expansion Leading-in Wire for Incandescent Electric Lamps." In accepting the Medal and Certificate from the Chairman, Doctor Eldred expressed his appreciation of this recognition of the Institute and said that in his opinion such awards would greatly stimulate the efforts of recipients in the field of physical research.

Dr. H. J. M. Creighton was then recognized and gave an account of the process of water-proofing fabrics, invented by Mr. Alfred O. Tate, of Cranston, Rhode Island, who had been awarded the Howard N. Potts Medal for his process. He then introduced Mr. Tate to the Chairman who presented him with the Medal and Certificate. Mr. Tate thanked the Institute for the high honor conferred upon him and expressed his great appreciation of it.

The paper of the evening on "The Delaware River Bridge between Philadelphia and Camden" was presented by Dr. Ralph Modjeski, Chief Engineer of the Delaware River Bridge Joint Commission. The speaker gave an account of the comparative study and considerations which lead to the adoption of the suspension type of bridge and described the salient features and characteristics of the design. The subject was illustrated by lantern slides from the engineers' drawings and views of the bridge as it will appear when completed.

A unanimous vote of thanks was extended to Dr. Modjeski and the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, October 5, 1921.)

HALL OF THE INSTITUTE,
PHILADELPHIA, October 5, 1921.

MR. CHARLES W. MASLAND *in the Chair.*

The following reports were presented for final action:

No. 2759: Screw Thread Comparator. The Edward Longstreth Medal to Governor James Hartness, of Springfield, Vermont.

No. 2768: "Once-Over" Tiller. The Edward Longstreth Medal to Mr. Thomas Willing Hicks, of Minneapolis, Minnesota.

No. 2773: Photo-Elastic Method of Determining Stress. The Howard N. Potts Medal to Dr. E. G. Coker, of the University of London, England.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, October 11, 1921.)

RESIDENT.

MR. W. L. DEMPSEY, 618 Perry Building, 1530 Chestnut Street, Philadelphia, Pennsylvania.

MR. LEON W. NICHOLS, 5840 Warrington Avenue, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

DR. RAYMOND F. BACON, Chemists Building, 50 East 41st Street, New York City, New York.

MR. A. W. K. BILLINGS, Canadian Engineering Agency, 115 Broadway, New York City, New York.

MR. CLARENCE R. CLAGHORN, 715 Continental Building, Baltimore, Maryland.

MR. GEORGE E. CABOT, East Valley Road, Montecito, Santa Barbara, California.

MR. JAMES M. CAIRD, Proctor's Building, 92 Fourth Street, Troy, New York.

MR. H. V. COES, 5901 Wayne Avenue, Germantown, Philadelphia, Pennsylvania.

MR. F. J. COLE, 640 South Hill Avenue, P.O. Box 459, Pasadena, California.

MR. PATRICK B. DELANY, South Orange, New Jersey.

MR. R. E. GILLMOR, Van Rensselaer Avenue, Stamford, Connecticut.

MR. BAYARD GUTHRIE, R.F.D. No. 2, Ocean Springs, Mississippi.

MR. RICHARD HOWSON, 36 Mansion Avenue, Haddonfield, New Jersey.

DR. JOHN PRICE JACKSON, 129 Coulter Street, Ardmore, Pennsylvania.

MR. I. N. KNAPP, 6813 Fifth Street, N. W., Takoma Park, District of Columbia.

MR. CONRAD LAUER, 233 Hortter Street, Germantown, Philadelphia, Pennsylvania.
MR. WILLIAM MAUL MEASEY, Box 208, Haverford, Pennsylvania.
MR. CHARLES W. SOULAS, 1108 Sansom Street, Philadelphia, Pennsylvania.
MR. CHARLES A. STONE, Stone & Webster, 120 Broadway, New York City, New York.
MR. S. WEINBERG, Brown Palace Hotel, Denver, Colorado.
MAJOR R. A. WIDDICOMBE, 4639 Beacon Street, Chicago, Illinois.

NECROLOGY.

Mr. Lewis Audenried, Eddystone, Pennsylvania.
Mr. Alfred E. Burk, 925 N. Third Street, Philadelphia, Pennsylvania.
Mr. George R. Henderson, The Aldine Hotel, Philadelphia, Pennsylvania.
Captain A. F. Lucas, 2300 Wyoming Avenue, Washington, District of Columbia.
Prof. J. W. Richards, Lehigh University, Bethlehem, Pennsylvania.
Mr. Paul L. Wolfel, Oliver Building, Pittsburgh, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

American Concrete Institute Proceedings. 1921.
BROUGHTON, H. H.—Electrical Handling of Materials. Vol. I. 1920.
Chemical Engineering Catalogue. 1921.
FOLTZER, JOSEPH.—Artificial Silk and Its Manufacture. 1921.
GOODALE, STEPHEN L.—Chronology of Iron and Steel. 1920.
GUNTHER, R. T.—Early Science in Oxford. Pt. 1—Chemistry. 1921.
JUDGE, ARTHUR W.—Aircraft and Automobile Materials of Construction. 1921.
Material Handling Cyclopedia. 1921.
Poor's Manual of Industrials. 2 vols. 1921.
Poor's Manual of Public Utilities. 1921.
ROYDS, R.—Heat Transmission by Radiation, Conduction and Convection. 1921.
ROYDS, R.—Heat Transmission in Boilers, Condensers and Evaporators. 1921.

GIFTS.

American Chemical Paint Company, Bulletin No. 10, Directions for Using Deoxidine. Philadelphia, Pennsylvania, 1921. (From the Company.)
American Reflex-lite Company, Booklet, Modern Indirect Lighting. Columbus, Ohio, no date. (From the Company.)
American Rolling Mill Company, Book, Armco in Pictures and Fact. Middletown, Ohio, 1921. (From the Company.)
Borden Company, Catalogue No. 14, Beaver Pipe Cutting and Threading Tools. Warren, Ohio, 1920. (From the Company.)
British (Terra Nova) Antarctic Expedition, Report on Terrestrial Magnetism. London, England, 1921. (From the Committee of the Captain Scott Antarctic Fund.)

Brown and Sharpe Manufacturing Company, Catalogue No. 28, Small Tools. Providence, Rhode Island, 1920. (From the Company.)

Bury Compressor Company, Bulletin No. 407, Bury Universal Air Compressors. Erie, Pennsylvania, no date. (From the Company.)

Carborundum Company, Catalogue No. 6, devoted to Carborundum and Aloxite Wheels for All Classes of Grinding. Niagara Falls, New York, 1917. (From the Company.)

Chuse Engine and Manufacturing Company, Bulletin No. 7, Chuse Non-releasing Corliss Engines. Mattoon, Illinois, 1921. (From the Company.)

Colorado Bureau of Mines, Annual Report for 1920. Denver, Colorado, 1921. (From the Bureau.)

Columbia Basin Survey Commission, Report of the Columbia Basin Irrigation Project. Spokane, Washington, 1920. (From the Commission.)

Consolidated Gas Company, Memorandum of Depreciation Charges of Railroads and Public Utilities. New York City, New York, 1921. (From the Company.)

Dake Engine Company, Catalogue No. 28, Contractors Equipment, Steam and Air Motors, Pneumatic Hoists, Marine Machinery. Grand Haven, Michigan, no date. (From the Company.)

Delta Star Electric Company, Bulletin No. 36, High Tension Outdoor Unit Type PM–36. Chicago, Illinois, 1921. (From the Company.)

Department of Public Utilities, Annual Reports of the Division of Water for 1918 and 1919. Cleveland, Ohio, 1919 and 1920. (From the Department.)

Diamond Power Specialty Company, Bulletin No. 137, Diamond Valve-in-head Soot Blowers. Detroit, Michigan, 1921. (From the Company.)

Donnelly Systems Company, Bulletin No. 25, One-Pipe Fractional Vapor-Vacuum System. New York City, New York, 1921. (From the Company.)

Edwards and Company, Catalogue No. 8, Electrical and Signaling Apparatus. New York City, New York, no date. (From the Company.)

Electric Arc Cutting and Welding Company, Handbook of Instructions for Setting Up and Operating the A-C Cutting and Welding Machine and Electrodes, Catalogue of Portable Welding and Cutting Apparatus. Newark, New Jersey, no date. (From the Company.)

Ellison, George, Catalogue Describing Electrical Appliances. Birmingham, England, 1921. (From Mr. G. Ellison.)

Enzor-Hoel Company, Catalogue No. 2, Electric Fixtures and Supplies. Columbus, Ohio, no date. (From the Company.)

Fairmount Park Art Association, Forty-ninth Annual Report. Philadelphia, Pennsylvania, 1921. (From the Association.)

Farr and Company, Manual of Sugar Companies. New York City, New York, 1921. (From the Company.)

Fralick, S. R., and Company, Catalogue No. 21, Bulletins No. 21-A, Conduit Fittings; No. 21-B, Conduit Hanging Materials; No. 21-C, Boxes; No. 21-D, Cutout Material, and No. 21-E, Blake Specialties. Chicago, Illinois, no date. (From the Company.)

Freeman-Riff Company, Bulletin No. 210, F-R Portable Conveyors. Terre Haute, Indiana, no date. (From the Company.)

Fulton Iron Works Company, Bulletin No. 300, Treatise Explaining Adjustment of Fulton-Corliss Valve Gear. St. Louis, Missouri, 1921. (From the Company.)

Greene, Tweed and Company, Catalogue of Rochester Automatic Lubricators. New York City, New York, no date. (From the Company.)

Greenfield Tap and Die Corporation, Catalogue No. 46, Small Tools. Greenfield, Massachusetts, 1921. (From the Corporation.)

Hagan, George J., Company, Bulletin No. LF 105, Standardized Heat Treating Furnaces. Pittsburgh, Pennsylvania, 1921. (From the Company.)

Heller Brothers Company, Catalogue No. 21, Tool Steels. Newark, New Jersey, no date. (From the Company.)

Hick, Hargreaves and Company, Ltd., Catalogues of Petrol Engines and Diesel Oil Engines. Bolton, England, no date. (From the Company.)

Hi-Voltage Equipment Company, Bulletin No. 2, describing Lightning Arresters, Choke Coils and Fuses. Cleveland, Ohio, no date. (From the Company.)

Hydro-Electric Power Commission, Thirteenth Annual Report for 1920. Toronto, Canada, 1921. (From the Commission.)

Illinois State Water Survey, Bulletin No. 16, Chemical and Biological Survey of the Waters of Illinois. Urbana, Illinois, 1920. (From the Survey.)

Indian Railway Conference Association, Proceedings of Bangalore Meeting, April, 1921. Bangalore, India, 1921. (From the Association.)

Institution of Naval Architects, Transactions, vol. 63. London, England, 1921. (From the Institution.)

Iowa Board of Railroad Commissioners, Forty-third Annual Report for 1920. Des Moines, Iowa, 1921. (From the Commissioners.)

Karge-Baker Corporation, Catalogue describing Karge Couplings. Phoenix, New York, no date. (From the Corporation.)

Kernchen Company, Catalogue of the Kernchen Siphonage Ventilator. Chicago, Illinois, no date. (From the Company.)

Knott, L. E., Apparatus Company, Catalogue of Scientific Instruments. Boston, Massachusetts, no date. (From the Company.)

Liverpool Engineering Society, Transactions, vol. 41. Liverpool, England, 1920. (From the Society.)

Longyear, E. J., Company, Bulletin No. 15, Shaft Sinking. Minneapolis, Minnesota, no date. (From the Company.)

Macbeth-Evans Glass Company, Book, Fifty Years of Glass Making. Pittsburgh, Pennsylvania, 1920. (From the Company.)

Machinery Company of America, Catalogue No. 33, Swages and Shapers. Big Rapids, Michigan, no date. (From the Company.)

Maganese Steel Founders' Society, Book No. 9, Specifications for Switches, Crossings and Guard Rails. Chicago, Illinois, 1921. (From the Society.)

Manistee Iron Works Company, Bulletin of Centrifugal Pumps. Manistee, Michigan, no date. (From the Company.)

Mehl Machine Tool and Die Company, Prospectus of Tool Service. Roselle, New Jersey, 1919. (From the Company.)

Monarch Engineering Company, Catalogue No. 102, Monarch Pumps and Water Systems. Dayton, Ohio, 1921. (From the Company.)

Mundie Manufacturing Company, Booklet of Zin-Ho Portable Air Compressors. Peru, Illinois, no date. (From the Company.)

National Moulding Press Corporation, Bulletin No. 1, National Asphalt Block Press. Brooklyn, New York, no date. (From the Corporation.)

National Pressed Steel Company, Handbook of National Pressed Lumber. Masillon, Ohio, 1921. (From the Company.)

New Jersey Department of Conservation and Development, Annual Report for 1920. Trenton, New Jersey, 1921. (From the Department.)

New York Public Service Commission, Second District, Fourteenth Annual Report for 1920. Albany, New York, 1921. (From the Commissioners.)

Nordling, K. E., and R. Bengtzon, Booklet of Ess-Tubes and Spiral Superheaters. Amal, Sweden, no date. (From Messrs. Nordling and Bengtzon.)

Northampton Polytechnic Institute, Catalogue for 1921–1922. London, England, 1921. (From the Institute.)

Northern Engineering Works, Bulletin No. 520-B, Electric Traveling Grab-Bucket Cranes; Bulletin No. 543, Northern Electric Hoists. Detroit, Michigan, no date. (From the Works.)

Oilgear Company, Bulletin No. 2, Variable Speed Hydraulic Power Transmissions. Milwaukee, Wisconsin, no date. (From the Company.)

Pacific Tank and Pipe Company, Catalogue No. 12, Mining Tanks. San Francisco, California, 1921. (From the Company.)

Pawling and Harnischfeger Company, Circulars, The New Shovel Attachment and The New Skimmer Scoop Attachment. Milwaukee, Wisconsin, no date. (From the Company.)

Pearson-Scott Company, Booklet, The Iron Man. Indianapolis, Indiana, no date. (From the Company.)

Pennsylvania Railroad Company, Seventy-fourth Annual Report for 1920. Philadelphia, Pennsylvania, 1921. (From the Company.)

Plymouth Cordage Company, Booklet, Plymouth Rope and the Merchant Marine. North Plymouth, Massachusetts, 1918. (From the Company.)

Protected Seat Valve Company, Catalogue No. 1, B. & O, Protected Seat Valves. Pittsburgh, Pennsylvania, no date. (From the Company.)

Purit Specialties, Ltd., Booklet No. 4, describing Electrical Appliances. Birmingham, England, 1921. (From the Company.)

Rail Welding and Bonding Company, Instruction Manual. Cleveland, Ohio, no date. (From the Company.)

Ransome, A., and Company, Ltd., Illustrated Catalogue of Patented and Improved Cask-Making Machinery. Newark-on-Trent, England, 1921. (From the Company.)

Rockwell, W. S., Company, Bulletin No. 223, Oil and Gas Burners. New York City, New York, no date. (From the Company.)

Reading Brass Works, Inc., Catalogue No. 1, Illustrating Standard Chandelier Brass Castings and Fittings. Reading, Pennsylvania, no date. (From the Works.)

Sankey, Joseph, and Sons, Ltd., Pamphlet, Sankey Steel Storage Bins. Wellington, England, 1920. (From Messrs. Sankey and Sons.)

Schramm, Chris D., and Son, Inc., Catalogue No. 11-C, Air Compressors, Portable and Stationary. West Chester, Pennsylvania, no date. (From the Manufacturers.)

Schutte and Koerting Company, Booklet, Industrial and Power Plant Appliances, Catalogue C, Section 1, Adhesion Oil Separator; Section 2, Dry Air Filter. Philadelphia, Pennsylvania, no date. (From the Company.)

Steward Davit and Equipment Corporation, Circulars describing Life Boats and Davits. New York City, New York, no date. (From the Corporation.)

St. Joseph's College, Catalogue, 1920-1921, and The High School Department, Annual Catalogue, 1920-1921. Philadelphia, Pennsylvania, 1921. (From the College.)

Sullivan Machinery Company, Bulletin No. 78-A, Sullivan Dry Vacuum Pumps. Chicago, Illinois, 1921. (From the Company.)

Tasmania Department of Mines, Underground Water Supply Paper No. 1. Launceston, Tasmania, 1921. (From the Department.)

Tracy Engineering Company, Bulletin No. 1, Quality of Steam by the Throttling Calorimeter. San Francisco, California, 1921. (From the Company.)

Union Electric Manufacturing Company, Catalogue No. 1380, Electrical Controlling Devices. Milwaukee, Wisconsin, 1921. (From the Company.)

United States Department of Commerce, Fourteenth Census of the United States taken in the Year 1920, vol. 1. Washington, District of Columbia, 1921. (From the Department.)

United States Department of Commerce, Foreign Commerce and Navigation of the United States for 1920. Washington, District of Columbia, 1921. (From the Department.)

University of Montana, Bulletin, Geology and Oil and Gas Prospects of Central and Eastern Montana. Butte, Montana, 1921. (From the University.)

University of Princeton, University Register for 1921-1922. Princeton, New Jersey, 1921. (From the University.)

Utility Safety Appliance Corporation, Pamphlet, Safeguarding Vertical Transportation. New York City, New York, no date. (From the Corporation.)

Virginia Geological Survey, Bulletin No. 2, The Geology and Coal Resources of Dickenson County, Virginia. Charlottesville, Virginia, 1921. (From the Survey.)

Waltham Department of Public Works, Annual Report for 1920. Waltham, Massachusetts, 1921. (From the Department.)

Ward-Leonard Electric Company, Bulletin No. 54, Vitrohm Resistance Boxes. Mount Vernon, New York, 1921. (From the Company.)

Warren Steam Pump Company, Bulletins No. 101, Steam Heat Vacuum Pumps; No. 102, Horizontal Duplex Piston Pumps; No. 103, Vertical Single Piston Pumps; No. 104, Horizontal Piston Pumps; No. 106, "Eclipse" Valve Gear for Single Pumps; No. 107, Duplex Outside Packed Plunger Pumps; No. 108, Duplex Automatic Pumps and Receivers; No. 109, Vertical Duplex Piston Pumps; No. 110, Single Outside Packed Plunger Pumps; No. 105, Useful Information for Designing and Operating Engineers. Warren, Massachusetts, no date. (From the Company.)

Watson and Sons, Bulletin No. 32-S, Duplitized X-ray Films and Accessory Apparatus. London, England, no date. (From Messrs. Watson and Sons.)

Wayne Tool Manufacturing Company, Catalogue No. 5, Reamers. Waynesboro, Pennsylvania, no date. (From the Company.)

Weller Manufacturing Company, Catalogue No. 35-D, Spiral Conveyors. Chicago, Illinois, no date. (From the Company.)

Wirt Company, Dim-A-Lite Catalogue. Philadelphia, Pennsylvania, 1921. (From the Company.)

Wittenmeier Machinery Company, Catalogue of Refrigerating Apparatus. Chicago, Illinois, no date. (From the Company.)

BOOK NOTICES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 117, The Drag of Zeppelin Airships, by Max M. Munk. 11 pages, diagrams, quarto. Washington, Government Printing Office, 1921.

This is a discussion of the results of tests with Zeppelin airships, in which the propellers were stopped as quickly as possible while the airship was in full flight. In this paper the author refers to the theory involved in these tests and to one scientifically interesting fact which can be derived from them and which has not yet been noted.

The chief general question concerning these tests is, of course: Does the negative acceleration of an airship with stopped propellers supply proper data for determining the drag of the airship when in uniform flight? This can not absolutely be answered in the affirmative, the two phenomena not being identical in principle. It is believed, however, that in this particular case the agreement is sufficient and that the data obtained from the test are the true or, at least, the approximate quantities wanted.

Report No. 121, The Minimum Induced Drag of Aerofoils, by Max M. Munk. 18 pages, quarto. Washington, Government Printing Office, 1921.

The paper contains some theorems concerning the arrangement of airplane wings which are of considerable practical interest. In particular, it shows the theoretical reasons for the decrease of drag which accompanies all increases in the aspect ratio or lateral extension of a wing. The efficiency of a given arrangement of wings may be calculated from the formulæ derived in this paper.

THE PRODUCTION OF EASTERN KENTUCKY CRUDE OILS. By Willard Rouse Jillson. Pamphlet, 8vo., 99 pages. Winchester, Kentucky, The Cumberland Pipeline Company, 1921. Private edition.

This is principally devoted to statistics of the production of wells in the eastern third of Kentucky, with comments, especially a discussion of the question of depletion. Several pages of prefatory matter give details of the oil-producing sands. The locations of the pools are indicated by a map. Oil supply is now such an important question that all exact information is welcome.

HENRY LEFFMANN.

A TEXT-BOOK OF PHARMACOGNOSY. By Heber W. Youngken, Ph.M., Ph.D., Professor of Botany and Pharmacognosy and Director of the Botanical Garden of the Philadelphia College of Pharmacy and Science. 8vo., 509 pages, contents, index and 350 illustrations. Philadelphia, P. Blakiston's Son and Company. Price $6.00 net.

In this well-written and well-printed volume, Dr. Youngken has included a vast amount of information upon one of the most important topics of applied microscopy. The great mass of crude drugs is drawn from the vegetable world, but the animal division yields a few. This material is subject to much adulteration, and also to many changes from conditions that are what may be called natural. Processes of decomposition of the type commonly called "spontaneous" go on frequently, and the attacks of insects are also productive of great injury. In the naming and describing of the drugs the author follows, of course, the United States Pharmacopœia and the National Formulary. An interesting summary is given of the history of pharmacognosy. The term was introduced by Seydler, in 1815, meaning simply the "knowledge of drugs," but, as noted, the fact that plants were in remote times collected for use as medicines shows that the earliest "herb doctors" had some system of recognition. The first written enumeration of such materials is that of Dioscorides, compiled about three quarters of a century before the present era. Centuries elapsed before further systematic work was published, it being stated that this was by an Arabian physician in the thirteenth century.

Turning to the matter of the book, after about 30 pages of preliminary information, the individual drugs are taken up and the characteristics of genuine samples are given. The adulterations are then detailed. The extensive use of excellent drawings and photographs adds much to the usefulness of the book. Most of these are presumably the work of the author, with some assistance of others and are very clear and distinct. In a few cases of sections of stems, the details are not minutely sharp, but always clear enough for recognition. In making photomicrographs of vegetable preparations, the use of a red screen will often be found advantageous. This lengthens the exposure considerably, but seems to give greater sharpness with ordinary light. It seems to the reviewer that the approximate degree of magnification should be entered with each figure.

Every page of the book gives evidence of thorough familiarity with the field, painstaking and persistent study of details, careful selection of data and vivid presentation of all the facts. The book will be of great service not only to the pharmacologist, but to the chemist engaged in analytical work in connection with supervision of food and drugs. It is one more gratifying evidence that American work is acquiring a dominance in scientific fields. A comprehensive table of contents and an excellent index are commendable features. The mechanical execution is of very high type. The text is clear and correct. The book is highly creditable to both author and publisher and will find a wide field of usefulness.

HENRY LEFFMANN.

WITHIN THE ATOM. A Popular View of Electrons and Quanta. By John Mills, Fellow, American Physical Society. 12mo, 215 pages, 36 illustrations in the text and 4 plates. No index. New York, D. Van Nostrand Company. Price, $2.00 net.

The theories that matter is discrete and that the ultimate particles are extremely minute, indivisible and indestructible date, in outline, from about five hundred years before the beginning of the present era. Unfortunately,

only scanty fragments of the writings of the early Greek philosophers have come down to us, and some of this material is known through quotations by writers who were not wholly in sympathy with those they quoted. From the limited information we have of scientific thought in this early age, it seems that a materialistic and agnostic spirit was quite marked, and Cumont has shown in his essay on "Astrology and Religion" that the earliest Greek philosophers opposed the view that the stars had any influence on human beings, declaring that all the stars were merely balls of fire. Lucretius, in the first century of the common era, gives a very elaborate discussion of the nature of matter, and compares the elements and compounds, respectively, to the letters and words of a language. All this early philosophy must have been reached deductively, as we have no reason to believe that experimental science had any noticeable development.

The book before us is offered, we are told in the preface, for readers who have no previous knowledge of electricity, mechanics or chemistry. There is no question of the author's familiarity with the modern views, and of the earnest effort he has made to present the complicated phases of these views in an attractive form, understandable by the ordinary reader. How far he has succeeded in this effort is a serious question. It would appear from the fact that on the title page he lays no claim to a college degree or a teaching experience, that he has had but little association with the student body, and, therefore, probably still less with the "man in the street," to whom the book is specially intended to appeal. Far be it from our intention to claim that a college degree is necessary to constitute a successful author of a text-book, but abundant experience demonstrates that capacity for giving instruction is rarely inborn, and even when the person has naturally such talent, much experience is needed to develop its full efficiency. Even the greatest geniuses are better for some training.

The literary style is in many places brilliant, but again often turgid and too highly latinized for easy comprehension by the general reader. The essay begins by representing the atom as composed of two classes of particles, "electrons" and "protons." The latter word seems to be coined, although it is introduced somewhat vaguely. It is presumably the positive nucleus of other writers. Reference is made to the mutually repellent powers of electrons and protons, respectively, and to their mutually attractive powers for each other. The analogy of sex attraction, which though very often used in this department of science, is wholly irrelative, is suggested, but is rejected because it will involve "connotations of animistic bias." This sentence will remind one of the conversation concerning Buck Fanshaw's funeral. Later, however, we are told that the picture that we form is like a state of society in which "promiscuity prevails." So the "triangle" is now in chemistry!

The reviewer is compelled to express the view that the literary form in which the matter of this book is cast has seriously injured it. New terms are unnecessarily introduced. The terminology of science grows fast enough without forcing. Whoever introduces a new term without good reason, let him be anathema. The words "pellate" and "tractate" are used as substitutes for "repel" and "attract" to avoid the "animistic bias." They are

apparently not the author's coinage, but their use seems unnecessary. The absence of an index is to be condemned.

The mechanical execution of the book is good; numerous clear illustrations and several fine plates will aid materially in understanding the several chapters. HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Die Technik der Elektrischen Messgeräte, von Dr. Ing. George Keinath. 448 pages, illustrations, 8vo. Munich and Berlin, R. Oldenbourg, 1921. Price, in paper, 112 marks.

Imperial Institute: Monographs on Mineral Resources with Special Reference to the British Empire; Silver Ores, by H. B. Cronshaw, B.A., Ph.D., A.R.S.M. 152 pages, illustrations, 8vo. London, John Murray, 1921. Price, in paper, 6 shillings, net.

The Transit: Published annually by the College of Applied Science, University of Iowa. Vol. 21, 70 pages, illustrations, 8vo. Iowa University, Iowa City, 1921.

The Photo Miniature, No. 183, Color Photography, an authoritative summary of the progress made toward the final solution of the problem, with a clear explanation of the principle underlying the methods of to-day and to-morrow. 144 pages, illustrations, 12mo. New York, Tennant and Ward, 1921. Price forty cents. (Contains a very well written and plain statement, by Dr. C. E. K. Mees, of the principles and present practice in color photography, giving several of the most recent suggestions for color cinamatography.)

U. S. Bureau of Mines: Bulletin 186, Investigations of Zirconium, with especial reference to the metal and oxide. Historical Review and Bibliography, by J. W. Marden and M. N. Rich. 152 pages, illustrations, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, June, 1921, by W. W. Adams. 22 pages, 8vo. Technical Paper 261. Oil-camp Sanitation, by C. P. Bowie. 32 pages, illustrations, 8vo. Washington, Government Printing Office, 1921.

Technical Books of 1920. A selection. 28 pages, 16mo. Brooklyn, New York, Pratt Institute Free Library, 1921.

National Advisory Committee for Aeronautics: Sixth Annual Report, 1920, including Technical Reports Nos. 83 to 110. 717 pages, illustrations, plates, diagrams, quarto. Technical Notes, No. 31. Crippling Strength of Axially Loaded Rods, by Fr. Natalis. 34 pages, plates, quarto. Technical Notes, No. 61, Performance of a Vane Driven-gear Pump, by R. H. Heald. 10 pages, diagrams, quarto. Technical Notes, No. 64, N. A. C. A. Recording Air-speed Meter, by F. H. Norton. 5 pages, plates and diagrams, quarto. Technical Notes, No. 70, The Effect of Staggering a Biplane, by F. H. Norton. 3 pages, diagrams, quarto. Washington, Committee, 1921.

CURRENT TOPICS.

The Swiss Commission on Atomic Weights.—*Helvetica Chimica Acta* (1921, iv, 449) gives the report of a commission appointed by the Swiss Chemical Society concerning the international revision of atomic weights. The commission consists of Bernoulli, Dutoit, Guye and Treadwell. The report, after the usual formal preamble, takes up the history of the work. It was in 1903 that the four leading chemical societies, those of America, Great Britain, France and Germany, agreed upon a joint action for annual revision of the table of atomic weights. During the early years of the world war, the reports appeared with the signatures of all four members, but the report for 1917 was signed only by the American, British and French members—Clarke, Thorpe and Urbain, respectively—and appeared only in the journals of those respective societies. In 1918 and 1919 the *Bulletin* of the French society did not publish the table. Since 1917, a table has appeared in the *Berichte* signed only by Ostwald, being merely a reprint of that of 1916.

It seems that this unrevised table has been maintained as official in Germany so that at the latest publication the following are among differences observed:

	International	German		International	German
Ar	39.9	39.88	N	14.008	14.1
B	10.9	11.00	Th	232.15	232.4

It is admitted on all sides that such a condition should not be continued. Confusion arises from the fact that German publications may use either the international or the German figures, generally the latter, the French chemists will, of course, be likely to use the former, and the Swiss chemists will hesitate between the two sets. Some complaints have arisen that the committee changes the weights too frequently and rather hastily. The effects of the war are seen in the recent publications, for determinations have been accepted which rest upon isolated work, not yet subject to control. The criticism is made that the international committee seems to be dominated by a tendency to adopt the newer figures without the necessary control.

The Swiss commission recommends that all the atomic weights not subject to revision since 1916 and found in both tables may be used, except that a reservation is made in the atomic weights of sulphur and carbon, too hastily changed in 1915–16, it being advised to adopt the values respectively of 12.00 and 32.07. As regards the other figures, the following rules are offered:

If the newest values differ from older by from 1/1000 to 1/10,000 they are to be admitted if confirmed by at least two independent methods.

If the differences are from 1/1000 to 1/100 admit them only if derived from at least three independent methods.

Applying these rules, the Swiss table will have but two modications, to wit: N = 14.008 and B = 10.90. It is preferred to mark F as 19.00 rather than 19.0. For atomic weights referred to oxygen, decimals suggesting an accuracy higher than 1/10,000 may be suppressed.

Referring to the atomic weights of radium and niton, it seems desirable to mark these so that the difference is exactly 4, hence niton may be assigned 222, radium being 226. For the ordinary work of the laboratory, especially in organic analysis, it is thought that no important error will occur if the round numbers for certain elements are used as heretofore—C 12, Cl 35.5, H 1 or 1.01, N 14, S 32. It is understood that unless the contrary is stated, analyses published in the Swiss journal will be based on these numbers.

It is further recommended that the revision be made standard for each decade, the various researches being accumulated during such a period being utilized in the revision. In the interval new figures to be introduced only if they are obtained by several different methods with concordant results.

The article is supplemented by a complete table for use of Swiss chemists, giving the names of the elements in three languages, the alphabetical arrangement being based on the French names.

H. L.

An Extension of the Range of the McLeod Gauge. A. H. PFUND. (*Phys. Rev.*, July, 1921.)—In the usual form of this gauge the pressure of a rarefied gas is derived thus. A known volume of the gas is driven by a rising column of mercury into a capillary tube where its volume can be measured and its pressure read from the difference of level of the mercury inside and outside the tube. If the original volume be 1000 times as great as the volume after compression, for example, then the original pressure in accordance with Boyle's Law was one-thousandth of the pressure after compression. "The sensibility limit has been reached when the length of the trapped air column and the difference in level of the two mercury columns are of the order of magnitude of 1 mm." The smaller the pressure of the trapped air that can be accurately measured the smaller the pressure of the uncompressed gas that can be measured in the gauge. Professor Pfund discards the measurement of pressure by the difference of level of mercury columns and replaces it by the more sensitive hot-wire gauge. A filament of fine tungsten wire was sealed

into the upper end of the capillary tube into which the air is compressed. It forms one of the four arms of a Wheatstone Bridge. If the bridge be balanced so that the accompanying galvanometer shows no deflection, and if the pressure of the gas surrounding the wire be changed, then the temperature assumed by the wire changes and its electrical resistance also changes. This is followed by a deflection of the galvanometer, the amount of which depends on the change of pressure of the gas. Hence from this deflection the amount of the change of pressure can be inferred from a calibration curve. The addition of the hot-wire gauge makes it possible to measure pressures one three-hundreth as small as can be measured without its assistance. The range of the improved gauge is from .275 mm. to 1.7×10^{-7} mm. of mercury.

G. F. S.

Thermal Expansion of Aluminum–Zinc Alloys.—A. SCHULZE. (*Physik. Zeit.*, July 15, 1921.).—For all the alloys examined in which the percentage of zinc ranged from 12.5 to 87.5 it was found that there was a temperature interval through which the length of the specimen determined for rising temperature was less at the same temperature than that obtained as it was cooling down. When temperatures are plotted as abscissas and lengths as ordinates, all the curves are nearly straight lines except at the interval mentioned above, where they resemble hysteresis curves in form. The largest area of such a quasi-hysteresis loop was got with an alloy, 25 per cent. aluminium and 75 per cent. zinc. For a piece of this composition one meter long at 20° the length at 270° with rising temperature was 107.65 mm., while at the same temperature but with falling temperature it was 109.62 mm. It had previously been known that such alloys having been heated sufficiently high and then allowed to cool undergo a change in crystallization at 256°. In this probably lies the explanation of the phenomenon.

G. F. S.

Improved Test for Cottonseed Oil.—In Halphen's test for the detection of the presence of cottonseed oil in olive oil, the reagent is a 1 per cent. solution of sulphur in a mixture of equal volumes of carbon disulphide and amyl alcohol. Equal volumes of the reagent and the oil are mixed, and heated for 15 minutes in a boiling aqueous solution of sodium chloride. A reddish color develops if cottonseed oil be present. R. A. KUEVER, of the University of Iowa (*Jour. Am. Pharm. Asso.*, 1921, x, 594–595), has improved both the reagent and the technic in this test. For the reagent, he uses a 1 per cent. solution of sulphur in a mixture of equal volumes of carbon disulphide and pyridine; the sulphur is dissolved in the mixed solvents by heating gently beneath a

reflex condenser. A sample of the oil to be tested is mixed with its own volume of the reagent; and the mixture is heated in a bath of mineral oil at a temperature of 115° C. A wine-red color develops almost instantly if cottonseed oil be present in the sample. The test will reveal the presence of as little as 1 per cent. of cottonseed oil in olive oil.

J. S. H.

Activities of the Reichsanstalt in 1920. (*Zeit. Instrumentenk.*, June, 1921.)—Among the manifold activities of the Charlottenburg institution the temperature coefficient of the resistance of pure metals received attention. Wire made from unusually pure nickel powder was found to have between 0° and 100° C. a coefficient of .0067, that is, when the temperature of the wire within this range was raised one degree its resistance increased by .0067 of its value at 0°. This is perhaps the largest result ever obtained in such a measurement with a pure metal. Small quantities of impurities affect the coefficient very differently according to their nature. Nickel with .3 per cent. cobalt, .1 per cent. iron and .05 per cent. silicon had a coefficient of .0063, not very different from that of pure nickel, while, on the other hand, specimens of nickel with .33 per cent. and .46 per cent. silicon respectively showed values of .0051 and .0048.

It was impossible to get cobalt wire of as great a degree of purity as in the case of nickel. The cobalt coefficient came out .0060 the highest value ever found for this metal.

In quite a diverse field the use of chromium leading-in wires has been investigated. Schott had called attention to the fact that the linear expansion coefficient of this metal is about the same as that of glass. Pure, commercial chromium could not, however, be made into wire. Heraeus in Hanau succeeded in producing a wire of chromium-nickel alloy of .3 to .4 mm. in diameter which works well when melted into lead glass. It carries from one-half to one ampere for long periods without detriment to the place of contact to the two materials.

G. F. S.

Contact Electricity. O. W. RICHARDSON. (*Science*, Sept. 30, 1921.)—For more than a century there has been a dispute as to the nature and cause of the difference of potential that manifects itself when two metals are put in contact. Volta himself in 1792 wrote "The metals . . . . can by themselves, and of their own proper virtue, excite and dislodge the electric field from its state of rest." In this opinion he has been supported by Davy, Helmholtz, and Lord Kelvin. The opposing view that in chemical action is to be sought the cause of the potential difference developed has received the adherence of Maxwell, Lodge and Ostwald.

Richardson's name always suggests to the physicist thermionic emission, that is the emission of ions and electrons by incandescent bodies. On superficial acquaintance there seems to be no connection between this phenomenon and contact electricity, but this would be a false conclusion. The author makes use of a study of what takes place within a portion of space severed from all communication with the rest of space—a method that yielded such good results in the matter of the pressure of radiation as well as elsewhere in the fields of physics. In such an enclosure there are two bodies, *A* and *B*, both hot enough to emit electrons, but *A* emits them faster than *B*. Thus *A* sends out more of the negatively charged electrons than it receives from *B*. It becomes positively charged, while *B* acquires a negative charge because it gains more electrons from *A* than it loses. Since the two bodies are oppositely charged they attract each other, and useful work may be done by letting them come together. It is a natural supposition that their contact will result in an equalization of potential. Let them be separated before the traffic in electrons can again establish opposite charges. After an interval such charges will again be in evidence and further work can be derived. By the continuance of this process all the heat energy will eventually be turned into useful work. Such a result is, however, in contradiction with the second law of thermodynamics. There must, therefore, be an error in the reasoning. One must choose between these horns of the dilemma, either the two bodies, *A* and *B*, must emit the same number of electrons or these two bodies are not discharged when they come into contact. Bodies do have different rates of emitting electrons. This is an experimental fact. The first alternative is accordingly ruled out and we are driven to accept the second. "It means that bodies have natural states of electrification whereby they become charged to definite potential differences whose magnitudes are independent of their relative positions. There is an intrinsic potential difference between *A* and *B* which is the same, at a given temperature, whether they are at a distance apart or in contact."

When the theory of the development of the potential difference is worked out this quantity is found to be a function of the absolute temperature and of the saturation current per unit area of the two bodies. Experiments made by Richardson show that a satisfactory agreement holds between the contact potential actually measured and that calculated from the formula derived theoretically.

Thus it seems possible that the long-standing dispute may be settled by an appeal to phenomena seemingly far afield from contact electricity.

G. F. S.

Problems in Physics. O. W. RICHARDSON. (*Science*, Sept. 30, 1921.)—"At the present time we have, I think, to accept it as a fact that the atoms consist of a positively charged nucleus of minute size, surrounded at a fair distance by the number of electrons requisite to maintain the structure electrically neutral. The nucleus contains all but about one two-thousandth of the mass of the atom, and its electrical charge is numerically equal to that of the negative electron multiplied by what is called the atomic number of the atom, the atomic number being the number which is obtained when the chemical elements are enumerated in the order of the atomic weights; thus, hydrogen = 1, helium = 2, lithium = 3, and so on. Consequently the number of external electrons in the atom is also equal to the atomic number. The diameters of the nuclei of the atoms are comparable with one-millionth of one-millionth part of a centimeter, and the problem of finding what lies within the interior of such a structure seems at first sight almost hopeless. It is to this problem that Rutherford has addressed himself by the direct method of bombarding the nuclei of the different atoms with the equally minute high-velocity helium nuclei (alpha-particles) given off by radioactive substances, and examining the tracks of any other particles which may be generated as a result of the impact. A careful and critical examination of the results shows that hydrogen nuclei are thus expelled from the nuclei of a number of atoms such as nitrogen and phosphorus. On the other hand, oxygen and carbon do not eject hydrogen under these circumstances, although there is evidence in the case of oxygen and nitrogen of the expulsion of other subnuclei whose precise structure is a matter for further inquiry. The artificial transmutation of the the chemical elements is thus an established fact. The natural transmutation has, of course, been familiar for some years to students of radioactivity. The philosopher's stone, one of the alleged chimeras of the mediæval chemists, is thus within our reach."

G. F. S.

The Mass Spectra of the Alkali Metals. F. W. ASTON. (*Phil. Mag.*, Sept., 1921.)—This is a continuation of one of the most splendid scientific campaigns ever undertaken. The objectives are no less than answers to these fundamental questions, "Why do certain elements have atomic weights that are integers?" "Why do other elements have atomic weights that are not whole numbers?" As element after element is examined by the methods of the positive rays, it is seen that those elements of integral atomic weight are not mixtures of elements but contain a single element, while those so-called elements of fractional atomic weight are made up of two or more elements, each of which has an integral atomic weight. The atomic weight of the mixture

depends on the proportions in which the constituent elements, the isotopes, are mixed in the ordinary chemical element.

To get positive rays of the alkali metals the anode in the discharge tube, a piece of platinum foil, was coated with a salt of the metal under investigation, and was heated by an electric current. For lithium the parabola method was used, but for the heavier metals the mass spectrograph was employed. The following table embodies the results:

Element	Atomic Number	Atomic Weight	Minimum No. of Isotopes	Mass of Isotopes in Order of Intensity
Lithium	3	6.94	2	7,6
Sodium	11	23.00	1	23
Potassium	19	39.10	2	39,41
Rubidium	37	85.45	2	85,87
Cæsium	55	132.81	1	133

"When this table is taken in connection with that of the elements given by the ordinary disharge-tube method, it will be seen that the mass-spectrum analysis of three groups of the periodic table—the halogens, the alkali metals, and the inactive gases—is now complete as far as the element cæsium; and with the possible exception of K(39) and the doubtful Cl(39) there are no isobares. The intermingling of the atomic weights so determined is very remarkable, and is particularly striking in the case of the ten consecutive integers representing the isotopes of bromine, krypton and rubidium—Kr, 78; Br, 79; Kr, 80; Br, 81; Kr, 82; Kr, 83; Kr, 84; Rb, 85; Kr, 86; Rb, 87. It is quite clear that the exact order of the chemical atomic weights has little significance and that the anomalies such as argon and potassium are merely due to the unequal relative proportions of their isotopic constituents."

G. F. S.

Reproductions of Manuscripts, Plates and Drawings Without a Camera.—*Le Procédé* gives an account of the procedure termed "Manul," which although patented some years ago, is just now attracting a good deal of attention in the technical journals. It is the invention of Max Ullman, who has made a partial anagram of his name as the title. *Le Procédé* claims that substantially the same principles were applied about 1890 by Yvon and more recently by Fontenay, the only important difference being that the French workers used gelato-bromide emulsions, while Ullman uses an egg albumin-bichromate film. The sensitive plate is placed in a frame provided with a glass front, the uncoated side of the plate being turned towards this glass. The document to be copied is placed with the text in contact with the sensitive surface, the frame closed and exposed to the light. Under these conditions, the light which passes

into the system is absorbed by the lines of the design, while it is reflected by the unprinted portions of the document; broadly speaking, it may be said that the amount of light acting on the sensitive surface where the high lights are, is double that which acts in the shadows. If, therefore, sufficient exposure is given, the high lights of the original will be, in the coating, completely insoluble, while the design will represent a somewhat soluble area. By development, a relief is produced from which copies can be obtained. The original patent does not give satisfactory details, but Aug. Albert, Professor at the Institute of Graphic Arts at Vienna, communicates to *Photographische Korrespondenz* some experiments on the procedure and claims to have obtained satisfactory results. The thick layer that results when ordinary gelatin bichromate mixtures are used is not applicable in the process, a very thin sensitive layer being necessary. Albert gives two formulas stating that both give good results. The sensitizing mixture should be spread by means of a roller, as it must be extremely thin and nearly colorless.

FORMULA I.

White of egg solution in water	25 c.c
Clarified liquid glue	20 c.c
Twenty per cent. solution of potassium bichromate	20 c.c

Mix thoroughly.

The white of egg should be beaten to a foam and then filtered. The glue solution is the same used in enamel work.

FORMULA II.

Water	60 c.c
Liquid glue	30 c.c
Ten per cent. sol. ammonium bichromate	24 c.c
Pure sugar (12.5 per cent. solution)	20 c.c

Mix thoroughly as before and add a few drops of glycerin. The materials used are not as clearly defined as they should be, but it is evident that the basis of one mixture is an albumin solution reinforced by gelatin, and that the commercial egg albumin and a high-grade gelatin can be used. In such case, a 14 per cent. solution should be used. The albumin should be in fine powder and dissolved in cold water. The other mixture relies practically on gelatin and sugar, thus being substantially the gum bichromate method. The main point in the process is to secure a thin and very transparent film.

The duration of exposure is a serious difficulty, and it is recommended to use a very strong light of constant power. It is likely that a number of trials will be required before any exactness can be obtained. The development should be in cold or at most very slightly warmed water. After this is completed, the plate is immersed in a

solution of fuchsin or some similar color, then into a yellow color (chrysoidin is recommended) in order to get a strong and non-actinic tint. After a short rinsing, the negative is used in the usual way for copying on metal.

In this connection, attention may be called to a process of copying without a camera, described and illustrated by Dr. Henry Leffmann at a lecture before The Franklin Institute and published in the JOURNAL OF THE FRANKLIN INSTITUTE, vol. 178 (1914), p. 743. This consisted simply in placing the sheet to be copied upon a glass plate that had been coated with luminous paint, the paint having been strongly activated by exposure to strong light. Upon the original sheet, a sensitive plate, film or development paper was placed and the luminous surface allowed to act for about ten minutes. Of course, the arrangement must be made in the dark and care taken that the sensitive surface is not exposed to the luminous one, except through the subject to be copied. For copying short letters or diagrams written only on one side of the paper the process is satisfactory. It will not answer for copying from papers containing matter on both sides as there will be confusion, but that objection seems to apply al o to the process above described. H. L.

Air Seasoning of Wood.—In coöperation with the sawmills and wood utilization plants throughout the country, the Forest Products Laboratory, Madison, Wisconsin, is organizing an extensive field study on the air seasoning of wood. This study, it is believed, will be of extreme interest to the lumber manufacturer and to the wood-using industries. The purpose is to determine the piling practice which will result in the fastest drying rates consistent with the least depreciation of stock, the least amount of required yard space, and the least handling costs. The study will be carried on concurrently on both hardwoods and softwoods. All the important commercial woods of the United States will eventually receive consideration.

The air seasoning of wood is an old practice. No systematic attempt has ever been made, however, to work out the exact conditions under which drying time and drying costs can be reduced to a minimum. It is not actually known which of the numberless methods of piling will give the quickest and the cheapest results under given climatic conditions. The new project will furnish a comparison of the effects of such piling variables as sticker heights, the spacings of boards in layers, the heights of pile foundations, and the directions of piling with relation to prevailing winds and yard alleyways.

The study is expected to decide whether from a business standpoint lumber should be dried partly at the mill and partly at the plant of utilization, or whether it should be completely dried at the mill. The data collected will also go a long way toward showing whether air seasoning or kiln drying is the more profitable.

A tentative working plan of the air seasoning study has been prepared by the Forest Products Laboratory, and copies are being

sent to the secretaries of the various lumber and wood-using associations, state foresters, forest school heads, and others eminently qualified to comment on the plan.

Coöperation in the air seasoning study is being offered on every side. As yet the plants at which the work will actually be done have not been definitely chosen, but the extreme interest already manifested indicates that there will be no difficulty in securing coöperation with plants ideal for the study. Actual field work will soon be well under way.

Present-day Shipping Problems.—In the presidential address of Sir William Joseph Noble, before the Northeast Coast Institution of Engineers and Ship-builders some of the problems of sea power were discussed, of course, from the British point of view. At the beginning of the war, the world's gross steam tonnage was 42½ tons, of which that of the United Kingdom represented nearly half in figures, but a larger proportion when efficiency was taken into full account About two-thirds of the British tonnage was less than fourteen years old, thus having the advantage in size and type. As a result half of the world's sea-borne trade was carried under the British flag, all other nations being more or less dependent thereon. During the war British tonnage decreased over 13 per cent. in the gross, but the actual reduction was larger, as the heaviest losses were among the largest ships. To-day the British tonnage represents but a little over one-third of the total, due in the main to the enormous expansion of the ship construction of the United States, which since 1914 has increased 570 per cent. France and Japan have also increased materially their merchant power.

"We must not lose sight of the fact that the war impressed on the other maritime nations the importance of merchant fleets, and they are making great efforts to establish large mercantile marines. Competition before the war was growing keener year by year, but it was comparatively small compared with the competition we shall have to face in the future. Japan in the East and the United States in the West are making strenuous efforts to retain some of the trades we lost to them during the war, and the friendly rivalry of these two Powers, added to the competition of our European neighbors, provides a task worthy of all our energies.

"Nothing but real peace will restore the security and the confidence we need. As one has pithily said—'There will be no peace of plenty until we have plenty of peace.' And we can have no assurance of peace so long as the governments of the world devote 20 per cent. of their expenditure to the maintenance of armaments and to preparations for war. To-day out of every

pound that we pay in taxes more than 12/- is spent on old and new wars. Before the war the U. S. A., Great Britain, France, Italy and Belgium together spent on armaments 228 millions sterling. After the war—with an impoverished world—the same countries are spending 1178 millions. Bankruptcy threatens most of the governments of the world, and it can only be averted by stopping this mad competition in armaments.

"My complaint about democracy is that it fails to face the economic basis of industry, it does not want to think things out to their logical conclusion and as a consequence endeavours to escape every shadow of discipline and personal obligation, seeking only material enjoyment, the things of the body and ignoring the things of the spirit."

H. L.

PRESS OF
J. B. LIPPINCOTT COMPANY
PHILADELPHIA

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MEETINGS

COMMITTEE ON SCIENCE AND THE ARTS. First Wednesday of each month, 8 P.M. (except July and August).

BOARD OF MANAGERS. Second Wednesday of each month, 3.30 P.M.

INSTITUTE. Third Wednesday of each month (except June, July, August and September), 8 P.M.

SECTION MEETINGS. Thursday Evenings (except week of Institute Meeting), 8 o'clock. October 1 to April 30.

CHANGES OF ADDRESS

Members are particularly requested to inform the Secretary of changes of address.

MEMBERSHIP.

Terms and Privileges.

THE MEMBERSHIP OF THE INSTITUTE is divided into the following classes, viz.: *Resident Members, Stockholders, Life Members, Permanent Members, Non-resident and Associate Members.*

Any one interested in the purposes and objects of The Institute and expressing a willingness to further the same may become a member when proposed by a member in good standing and elected by the Board of Managers.

TERMS.—Resident members pay Fifteen Dollars each year. The payment of Two Hundred Dollars in any one year secures Life Membership, with exemption from annual dues.

STOCK.—Second-class stockholders pay an annual tax of Twelve Dollars per share, and the holder of one share is entitled by such payment to the privileges of membership.

PRIVILEGES.—Each contributing member (including non-residents) and adult holder of second-class stock is entitled to participate in the meetings of The Institute, to use the Library and Reading Room, to vote at the Annual Election for officers, to receive tickets to the lectures for himself and friend, to attend the Section meetings and to receive one copy of the JOURNAL *free* of charge, except associate members, who may not take part in elections.

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ASSOCIATE MEMBERS.—Associate members are accorded all the privileges of The Institute, except the right to vote or hold office, upon the payment of annual dues of Five Dollars. This class of membership is limited to persons between the ages of seventeen and twenty-five years. Upon reaching the age limit they become eligible to the other classes of membership.

RESIGNATIONS *must be made in writing, and dues must be paid to the date of resignation.*

For further information and membership application blanks address the SECRETARY OF THE INSTITUTE.

AWARDS BY THE INSTITUTE

The following awards are made by The Franklin Institute:

The Franklin Medal (Gold Medal and Diploma).—This medal is awarded annually from the Franklin Medal Fund, founded January 1, 1914, by Samuel Insull, Esq., to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

The Howard N. Potts Medal (Gold Medal and Diploma).—This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

The Edward Longstreth Medal of Merit (Silver Medal and Diploma).—is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products of superior excellence or utilizing important principles; and for papers of first importance that have been published in its JOURNAL.

The Edward Longstreth Medal of Merit (Silver Medal and Diploma).—This medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance.

The Certificate of Merit.—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices and for papers of special merit that have been published in its JOURNAL.

The Boyden Premium.—Uriah A. Boyden, Esq., of Boston, Mass., has deposited with THE FRANKLIN INSTITUTE the sum of one thousand dollars, to be awarded as premium to "any resident of North America who shall determine by experiment whether all rays of light, and other physical rays are or are not transmitted with the same velocity."

For further information relating to these awards apply to the Secretary of the Institute.

NOTICE is hereby given that THE FRANKLIN INSTITUTE, through its Committee on Science and the Arts, proposes to award

THE HOWARD N. POTTS GOLD MEDAL

To

DR. E. G. COKER

UNIVERSITY OF LONDON

For his

PHOTO-ELASTIC METHOD OF DETERMINING STRESS

Any objection to the above proposed award, based on evidence of lack of merit, should be communicated within three months of the date of this notice to the Secretary of THE FRANKLIN INSTITUTE, Philadelphia.

R. B. OWENS,
Secretary

HALL OF THE INSTITUTE
November 1, 1921

PAMPHLET REPRINTS *of* LECTURES *and* OTHER CONTRIBUTIONS

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